Sandia National Laboratories

Energy, Climate, & Infrastructure Security

FY14 STRATEGIC PLAN

The National Solar Thermal Test Facility (NSTTF) at Sandia National Labs.

Sandia Heuristic Intelligent Network Imaging (SHINI) displays network activity offering cyber-security practitioners a visually appealing way to display and view security log data.

Ear-plug-sized samplers, with silvery microvalves and solder connectors, seemingly hang poised to sample gases relevant to climate and weather.

VISION

To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

Message from the VP

Access to reliable, affordable, and sustainable sources of energy is essential for all modern economies. Since the late 1950s, we Americans have not been energy self-sufficient. Our addiction to foreign oil and fossil fuels puts our economy, our environment, and ultimately our national security at risk. Furthermore, there is a growing recognition of the requirement to balance our need for plentiful, low-cost energy, with an inherent responsibility to steward the natural environment. The U.S. does not face this challenge alone. As the world continues to become more connected, our collective futures are inextricably linked, and energy lies at the core of global interactions. Meeting our growing energy needs and how we manage the impacts on climate change will have profound ramifications on the global economy and ultimately on global geopolitical stability.

Sandia has a long history addressing the nation's energy challenges, beginning in the 1970s when our nation initiated its push toward energy independence. In 2010, Sandia combined programs in energy, climate, and infrastructure to create a new strategic management unit (SMU) that better leverages and integrates these three interrelated missions. Today, Sandia science and engineering expertise derived from our nuclear weapons heritage supports programs in solar and wind power for electricity generation, combustion science, nuclear repository design, and others. In FY10, our programs totaled approximately $300M and include national and international activities supported by three federal agencies and industry.

The Energy, Climate, and Infrastructure Security (ECIS) SMU leads and manages this mission area. Our heritage as a national security laboratory brings a unique perspective to addressing the new challenges and opportunities outlined by President Obama and the current administration. "Each of us has a part to play in a new future that will benefit all of us. As we recover from this recession, the transition to clean energy has the potential to grow our economy and create millions of jobs—but only if we accelerate that transition." (President Obama, June 15, 2010).

In this document you will see that we have developed a strategy that provides a roadmap for Sandia's research and development priorities: to accelerate development of reliable, affordable, and sustainable sources of energy; to be prepared for and understand potential consequences of climate change; and to ensure a safe, secure, and reliable energy delivery infrastructure. Combined together, these address the three main national challenges recently highlighted by the President's Council of Advisors on Science and Technology (PCAST), e.g., economic competitiveness, the environment, and energy security.

Looking toward the future, our success in serving the nation in the energy area continues to rely on our workforce. My vision for Sandia is to continue to build and sustain a diverse workforce composed of individuals who know that they are an important part of Sandia because they are valued, included, treated with respect and dignity, and are fully productive contributors to mission success.

Steve Rottler, Vice President
Energy, Climate, & Infrastructure Security SMU

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Executive Summary

Strategic Framework

The Energy, Climate, and Infrastructure Security (ECIS) Strategic Management Unit (SMU) Strategic Plan documents the long-range planning process to define its vision, objectives, goals, and portfolio of research to support Sandia's national security mission.

Our strategy is based on our role as a national security laboratory to address the nation's most daunting science and technology challenges within the national security context. Our plan is informed and guided by the five Sandia Laboratory objectives:

- Deliver with excellence on our commitments to the unique nuclear weapons mission
- Amplify our national security impact
- Lead the complex as a model 21st century government-owned contractor-operated laboratory
- Excel in the practice of engineering
- Commit to a learning, inclusive, and engaging environment for our people

Within this context, the objectives and goals developed by this SMU seek to both leverage and enhance key competencies associated with our nuclear weapons (NW) mission in order to amplify our contributions to broader national security in energy, climate, and infrastructure. The work of ECIS aims to further our engineering excellence with an emphasis on connecting deep science to engineering solutions. Finally, all of our work will be conducted in a manner that puts people first, assures the safety and health of employees and the public, protects the environment, and guards classified and other sensitive information.

The vision and set of enduring ECIS objectives described in this plan are congruent with foundational Sandia competencies built over decades. These competencies grew out of our historic mission in NW and a synergistic environment in which capabilities and expertise from our complementary missions support and strengthen one another. Ultimately, our mission is to enhance the security of the nation. In this SMU, due to the nature of the mission, the private sector has a unique and important role that is reflected in our objectives, because it is there that most energy and infrastructure technologies and solutions are deployed. Our overarching objectives are driven by both our historical contributions as well as our fundamental role for the government as a national laboratory. These objectives are as follows:

- Anticipate and enable government policy and regulatory decisions
- Steward competencies to support inherently government functions and services
- Accelerate private-sector deployment of solutions to meet U.S. policy objectives
- Support U.S. international engagement to solve national security challenges

As we developed our strategy and plan from these objectives, we faced the unique challenge that the nation does not currently have a well-articulated energy policy nor does the Department of Energy (DOE) have an enduring set of priorities and roadmaps that provide high-level integrated guidance. The DOE is now engaged in a Quadrennial Technology Review process, to which Sandia has contributed, to develop a framework that, in the future, we will be able to use for such guidance. While this is not yet available nor are clear governmental policies and priorities complete, there is general consensus at the national, regional, and state level on the most significant problems and challenges to our national security in this area. In our planning process, we reviewed these challenges and selected a set of seven national-level problems across the energy, climate, and infrastructure sectors that reflect our priorities and guiding framework. These are

- Reduce our dependence on foreign oil
- Increase deployment of low-carbon stationary power generation
- Understand risks and enable mitigation of climate-change impacts
- Increase security and resiliency of critical infrastructures
- Strengthen the nation's science & technology (S&T) base in energy, climate, and infrastructure

From these challenges, we then created a set of five-year, outcome-focused goals that are consistent with our national laboratory role, our unique competencies, and our objectives. Each of these is described more fully in the following sections.

40 Years of Sandia Contributions to the Nation's Energy Challenges

No modern nation is secure without an adequate supply of safe, assured, affordable, and environmentally sound forms of energy. Sandia's national security mission has driven the development of a broad range of programs in the energy area. These programs are built on the expertise and capabilities of Sandia's nuclear weapons legacy and continue to synergistically benefit from and strengthen this ongoing heritage.

The energy crisis of the 1970s was the catalyst of Sandia energy programs. For example, Sandia's strength in combustion science was directly stimulated by the oil crisis and has grown to a world-leading program. Results of this work have significantly improved internal combustion engine fuel efficiency through long-standing partnerships with automotive manufacturers. The Combustion Research Facility (CRF), a DOE Office of Science (SC) collaborative facility, was established in 1980 to bring together basic and applied research to improve the nation's ability to use and control combustion processes. A collaboration of CRF and modeling/simulation researchers with Cummins resulted in a 2007 diesel engine designed solely with computer modeling and analysis tools. Cummins achieved a 10%–15% reduction in development time and cost as they achieved a more robust design, improved mileage, and met all environmental and customer constraints.

During this same period, Sandia scientists and engineers established programs to support the Nuclear Regulatory Commission by providing independent technical expertise in nuclear reactor safety and reliability. Over 30 years of research into severe accident phenomenology has resulted in Sandia's MELCOR (Methods for Estimation of Leakages and Consequences of Releases) code which is now the preeminent tool to model severe accident progression in light water reactor power plants. It is being applied today as a key element of the U.S. support to Japan's Fukushima reactor crisis.

Sandia's programs in renewable energy were also initiated in the 1970s. Capabilities to model wind turbine blade configurations in a range of wind conditions and to predict their fatigue life were developed. Through partnering with universities and industry, Sandia has worked to advance the state of knowledge in the areas of materials, structurally efficient airfoil designs, active-flow aerodynamic control, and sensors. Sandia continues its applied research to improve wind turbine performance, reliability, and reducing the cost of energy and has participated in all aspects of wind-turbine blade design, manufacturing, large-scale testing, and system reliability.

Sandia has played a key role in developing solar technologies for commercial power-plant use. We have had responsibility for the materials-science work and computer codes that enable advanced designs. In the mid-1980s, Sandia partnered to build Solar One, the nation's largest solar power plant. To improve its efficiency, Sandia led an effort to develop molten salt energy-storage technology and proved it capable of operating smoothly through intermittent clouds and generating electricity long into the night. Many of the solar technologies developed at Sandia are being commercially deployed here and across the globe. Complementary work now going on at Sandia and elsewhere could also result in transportation fuels and chemicals from solar thermal technology.

Our concentrated solar power (CSP) research includes dish-Stirling engines—a parabolic-dish reflector with the externally heated Stirling engine. Sandia studied the basic thermodynamics to evaluate the prospects for commercialization. This research resulted in the system called the SunCatcher™—developed in partnership with Stirling Energy Systems (SES) of Phoenix, Arizona. It holds the world's record for solar-to-grid efficiency (31¼%) and has a full-year sunrise-to-sunset efficiency of ~25%—double that of other solar power systems.

One of the critical issues with "alternative" power generation is integrating that power into the local utility's network and, ultimately, into the national power grid. During the 1980s, Sandia initiated the Distributed Energy Technology Laboratory to integrate emerging energy technologies into new and existing electricity infrastructures. Sandia's research spans generation, storage, and load management at the component and systems levels and examines advanced materials, controls, and communications to achieve the Lab's vision of a reliable, low-carbon electric infrastructure.

These past successes and future accomplishments rely on our strong foundational science programs. In early 2009, Science Watch® published the results of its survey of scientific literature in the energy journals listed in the Science Citation Index. They identified Sandia as the most-cited institution in this research category, with 4,147 citations to its 395 papers published between 1998 and 2008. In the 21st century, Sandia has expanded its energy programs and partnerships to include climate research (because power generation and energy use are primary contributors to climate instability) and energy infrastructure security (because, as we integrate renewable energy power into the national power grid, we must initiate fundamental improvements). As it has since its founding, Sandia is working to provide the foundational science and engineering to underlie the nation's security. The Energy, Climate, and Infrastructure strategic management unit is working toward this goal with regard to our energy future.

National Security Missions

Since the late 1950s, we Americans have not been energy self-sufficient. Our addiction to foreign oil and fossil fuels puts our economy, our environment, and ultimately our national security at risk. Furthermore, there is a growing recognition of the requirement to balance our need for plentiful, low-cost energy, with an inherent responsibility to steward the natural environment. With the growth of complexity of our energy supply has come the complexity of our infrastructure and the importance of its resilience and security. The U.S. does not face this challenge alone. As the world continues to become more connected, our collective futures are inextricably linked, and energy and its infrastructure lie at the core of global interactions. Meeting our growing energy needs and how we manage the impacts on climate change will have profound ramifications on the global economy and ultimately on global geopolitical stability.

Achieving a sustainable future requires solutions to some difficult national-scale problems. Using our unique competencies and objectives as a guide, we have selected the following national challenges as the framework for determining our goals and milestones.

Reduce our dependence on foreign oil

Transportation by automobiles and trucks accounts for 71% of U.S. petroleum use.[1] In 2012, 57.3% of the oil consumed was imported[2] and 36.4% of that[3] comes from unstable states. A certain and significant part of any path toward reducing oil use is to develop more fuel efficient power conversion systems for vehicles. Current DOE program targets are to improve light-duty engine fuel efficiency by 50% and heavy-duty engine fuel efficiency by ~25% over the dominant engines on the road in each respective vehicle class. Such engine fuel-efficiency improvements alone would reduce domestic petroleum consumption by as much as four billion barrels per day. DOE is pursuing advanced biofuel research that will use sustainable biomass (e.g., lignocellulose and algae) that does not compete with food production to generate fuels that are "drop-in" replacements for today's gasoline, diesel, and jet engines. Sandia is a key partner of the DOE-funded Joint BioEnergy Institute (www.jbei.org), a facility that is developing new conversion technologies that will enable the commercialization and deployment of these advanced biofuels that are capable of displacing a significant portion of the ~200 billion gallons of petroleum consumed by the nation's transportation sector annually.

Increase deployment of low-carbon stationary power generation

The clean energy sector is undergoing tremendous growth with global new investments reaching $211B in 2011, up 32% from $160B in 2009 and nearly six and a half times the $33B achieved as recently as 2004.[4] Policy is

1. U.S. Energy Information Administration, "Annual Energy Review 2011," Figure 2.0: Primary Energy Flow by Source and Sector, 2010, http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf, p. 37.
2. U.S. Energy Information Administration, "International Energy Statistics: Total Petroleum Consumption," http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=5&pid=5&aid=2, (accessed on 25-July-2012).
3. U.S. Energy Information Administration, "U.S. Imports by Country of Origin," http://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbl_a.htm, (accessed on 25-July-2012).
4. United Nations Environment Programme, "Global Trends in Renewable Energy Investment 2011: Analysis of Trends and Issues in the Financing of Renewable Energy," (ISBN: 978-92-807-3183-5), p. 12 [http://www.unep.org/pdf/BNEF_global_trends_in_renewable_energy_investment_2011_report.pdf].

playing a central role in this development. Renewable portfolio standards, laws requiring electricity providers to obtain a minimum percentage of their power from renewable energy resources by a certain date, have been adopted by over 30 U.S. states and many countries. For electrical utilities to meet these standards on a large scale, they must build new generating capacity that uses wind, solar, biomass, geothermal, or hydropower.

Understand risks and enable mitigation of climate-change impacts

Hazards stemming from greenhouse gas (GHG) emissions are fundamentally different from those of previously identified acid-rain-producing pollutants. Once we curtailed those other emissions, natural atmospheric processes neutralized the pollutants relatively quickly, and the environment began to recover. Carbon dioxide's effects are more subtle and slower acting, requiring ~100 years to break the molecule down. Climate instability could create geopolitical disruptions, changing the global balance of power. A sound understanding of the potential socio-economic changes driven by climate is essential. Sandia's extensive competencies in systems analysis and uncertainty quantification couples with our foundational research capabilities to allow us to provide policy makers with usable (properly formulated and properly communicated) information that assists them in understanding these risks.

Increase security and resiliency of critical infrastructures

Reliably delivering energy to its end-use points is vital to our national security and economic prosperity. Manufacturing and commercial enterprises function most efficiently when electrical energy is delivered smoothly and predictably. To function as they are intended, our military's installations and tactical and training operations all require secure, uninterrupted access to energy. In 2009, the Department of Defense (DoD), the largest U.S. energy consumer, spent $3.8B to power its fixed installations—representing about 28% of total DoD energy costs (that fraction is higher in peacetime, when the military is not consuming large amounts of operational energy).[5]

The Galvin Electricity Initiative found that each day roughly 500,000 Americans spend at least 2 hours without electricity in their homes and offices. Such outages cost our economy $150B each year. [6] A power-grid failure affects other critical infrastructure such as hospitals, fire and rescue, and military and police agencies—putting these security and safety institutions in jeopardy. An intentional disruption could have even greater consequences. Sandia is helping the U.S. maintain it global competiveness by helping industry redesign the national electric grid infrastructure to be resilient enough to swiftly compensate for interruptions and flexible/intelligent enough to incorporate the planned renewable energy sources (with their inherent variability in power generation).

5. Robyn, D., "Statement of Deputy Under Secretary of Defense for Installations and Environment before the House Armed Services Committee Subcommittee on Readiness," February 24, 2010, p. 2, [http://www.acq.osd.mil/ie/download/robyn_testimony022410.pdf].

6. The Galvin Electricity Initiative, "The Electric Power System Is Unreliable," http://galvinpower.org/casetransformation/power-system-unreliable, (accessed on 25-Mar-2011).

Strengthen the nation's S&T base in energy, climate, and infrastructure

To overcome looming issues in energy generation, infrastructure security, and climatic effects, the nation requires science-based technological advances—not only in applied areas to refine and improve existing technologies, but in foundational science that will underlie the next generation of transformative technologies that will address the roots of these energy-infrastructure-climate challenges. It is clear that how we address and eventually meet these needs will have a broad impact on our standard of living and the national economy. Effective solutions will require scientific breakthroughs and truly revolutionary developments.

The Energy, Climate, & Infrastructure Security Strategic Management Unit

Vision

To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

10-Year Objectives

Anticipate and Enable Policy and Regulatory Decisions

Anticipate and enable sound government policy and regulatory decisions by providing timely and objective technology assessments and systems analyses.

Accelerate Solutions

Accelerate U.S. industries' innovation, development, and successful deployment of solutions to the nation's most challenging energy, climate, and infrastructure problems to meet U.S. policy objectives.

Steward Competencies

Create and steward enduring science, systems, and security competencies to support inherently government functions and services and anticipate national security challenges.

Support International Engagement

Support U.S. leadership in global energy, climate, and infrastructure challenges through strategic international engagement.

Guiding Principles

Our strategy has been guided by two central concepts:

- Industry plays the leading role in providing and adopting new energy and climate technologies.
- Policy and regulatory decisions at all levels of government drive the implementation of any new approaches to our nation's energy, climate, and infrastructure security.

ECIS Program Structure

The ECIS SMU has four principal program areas each led by a director: Energy Security, Climate Security, Infrastructure Security, and Enabling Capabilities. Each program area has a set of five-year goals, aligned with the SMU objectives and national challenges that drive our internal investments to accelerate development of reliable, affordable, and sustainable sources of energy; be prepared for and understand potential consequences of climate change; and ensure a safe, secure, and reliable energy delivery infrastructure. Program development resources are directly tied and tracked to the SMU program area goals. Our SMU goals are not intended to be fully comprehensive for the entire set of SMU activities but instead form the principal roadmap for priority investments. They align with federal program priorities, our current activities and competencies, and our focus for future impact.

Energy Security Program Area

The Energy Security program area works to accelerate the development of transformative energy solutions that will enhance the nation's security and economic prosperity.

Energy security research at Sandia seeks to address key challenges facing our nation and the world. We work with the energy industry to improve current solutions and develop the next generation of technologies to convert, store, or use energy.

The ECIS SMU spearheads research into energy alternatives that will help the nation reduce its dependence on fossil fuels, combat the effects of climate change, and strengthen our energy security by providing new alternative fuel sources. Sandia's long history with geothermal, solar, and wind energy research has seen a vast increase in effort and intensity over the past 15 years and has also been supplemented in recent years with efforts in biologically based fuels: biomass from nonfood plant sources and algae—both of which can be grown on land unsuitable for farming. Sandia researchers are also pushing back the boundaries of the energy frontier with revolutionary projects like Sunshine to Petrol, which converts CO_2 and water into synthetic fuels.

Sandia's Energy for Transportation activity studies reacting flow fluid dynamics, combustion chemistry, engine combustion, thermal/ fluid mechanics and heat and mass transfer, and hydrogen & combustion technologies to develop a science-based, first-principles understanding of combustion's properties and behavior in order to help industry:

1. Improve current engine technologies to be more efficient,
2. educe or eliminate a variety of harmful engine emissions, and
3. develop the next generation of engines that can efficiently use new fuel formulations and low-carbon alternative fuels that will help us reduce our impact on the environment.

Our researchers also work to improve the processes in the nuclear power enterprise by perfecting new concepts like the small modular reactor (SMR) that will contribute to the next generation of nuclear power generation and by developing options for disposal of waste from this important electric power source.

ENERGY SECURITY GOALS

1. Develop advanced technologies and systems that will enable renewable energy penetration to grow from 13% (in 2011) to 20% by 2020 in the U.S. power grid and at military installations.

Both the DOE and the DoD have set aggressive goals to increase the penetration of renewable energy resources in U.S. civilian and military infrastructures, respectively. A spectrum of renewable-energy technology options will be needed to meet diverse load demands, climate constraints, and mission requirements. Sandia supports this goal through innovative research and development (R&D), testing and evaluation, and system demonstration and deployment of novel wind, water power, photovoltaic (PV), CSP, and geothermal energy technologies. Sandia executes on this goal while addressing the energy surety attributes of safety, security, reliability, sustainability, and cost effectiveness to provide the most robust renewable-energy technology options.

2. Create nonpetroleum-based liquid transportation fuel options such as solar fuels and biofuels.

The nation has a variety of options for "energizing" or fueling the transportation section, but alternatives to petroleum pose challenges in terms of cost, infrastructure compatibility, scale, and in some cases, technical feasibility. To address the nation's vulnerabilities with regard to energy security in the transportation sector, Sandia is advancing two "alternative fuel" options: solar fuels and biofuels. In particular, Sandia aims to demonstrate technologies capable of producing fuel from sunlight at 10% lifecycle efficiency or greater and strives to develop advanced conversion technologies for fungible biofuels derived from lignocellulosic biomass and algae.

Given today's transportation energy infrastructure and the effectiveness of our current suite of liquid fuels, replacement solutions will both be difficult and take time to develop. Sandia has leveraged existing capabilities and resources to begin to answer some of the fundamental questions and approaches to this dilemma. Initial results have shown great promise and support the viability of efficiently and affordably producing clean fuels from the sun and domestic biofuel resources. Industry investments and partnerships will be critical to fully realize the opportunity solar fuels present.

Our multi-institutional Sunshine to Petrol team is working to develop/demonstrate 12.5% sunlight-to-syngas energy conversion and analysis for a system design to achieve >6% end-to-end sunlight to fuel and a roadmap to >10% lifecycle sunlight-to-fuel. The team has built a prototype thermochemical engine which has been tested at Sandia's National Solar Thermal Test Facility (NSTTF). Sandia participation in the Joint Bioenergy Institute (JBEI) is focused on developing and demonstrating fungible biofuels from biomass and algae. Sandia leads the lignocellulosic deconstruction efforts of this exciting multi-institutional endeavor.

3. Develop reactor design and support systems to demonstrate the application of small, modular reactors to fulfill DoD mission goals for energy security.

To address energy security while simultaneously enhancing mission assurance at domestic facilities, the DoD will accelerate innovative energy and conservation technologies from laboratories to military end users. The surety microgrid concept is to place power-generating facilities and energy storage within the military installation. SMRs have considerable DoD appeal—primarily for their matched power output and the possibility of location within DoD bases for grid independence and security. SMRs have DOE interest for their commercial appeal primarily for their expected lower capital costs to first power, their size and modular scalability, and their benefits of carbon-free energy production.

Sandia capabilities present an opportunity to provide the systems analysis necessary for the demonstration of nuclear power as an effective solution at the right price for mutual DOE and DoD energy security goals. Sandia's assessments of military energy security, activities in DoD logistic support, SMR design and construction, and reactor safety assessment position us to facilitate the DOE demonstration of an SMR at a DoD base.

4. Complete a deep borehole disposal system demonstration project with industry that will transform nuclear waste management.

The U.S. nuclear industry has produced about 62,500 metric tons of spent nuclear fuel. Congress assigned responsibility to the DOE to site, construct, operate, and close a repository for the disposal of spent nuclear fuel and high-level radioactive waste.

With the closing of the Yucca Mountain site, the nation is exploring the options for the safe disposal of this high-level radioactive waste. Due to an emphasis on mined repositories and concern regarding retrievability, deep borehole disposal (DBHD) is a concept that has been discussed for many years, but never pursued despite several advantages. A full-scale demonstration of a DBHD system will

- secure U.S. leadership in repository sciences;
- close the fuel cycle with permanent, secure waste disposal;
- address political/ regional equity concerns over hosting a single repository;
- provide factual data to support analysis of cost savings; and
- create a permanent disposal method that is highly proliferation resistant.

5. Provide for the science-based design tools necessary for industry to reduce carbon dioxide and petroleum footprint of the transportation fleet by 25%.

Transportation by automobiles and trucks accounts for about 71% of our oil use and one-third of our GHG emissions. The American Clean Energy and Security Act of 2009 describes goals for clean energy, energy efficiency, reducing GHG emissions, and creating clean-energy jobs. A certain and significant part of any path toward reducing both oil use, and concurrently, GHGs is to develop more fuel-efficient power conversion systems for vehicles and accelerate the introduction of low-net-carbon fuels.

The potential impact of fuel-efficiency improvements on reducing oil use and GHG emissions is enormous. As a nation, we urgently need to provide faster innovation, development, and introduction of high-efficiency, clean power sources for vehicles. Such investments are needed to grow jobs and bolster U.S. leadership in transportation.

Because no single technology is the panacea for the future, it is incumbent to work on each advanced technology with the expectation that the market will determine the mix of engines powering our vehicles by mid-century.

The Transportation Energy element of Energy Security is working on future ultra-efficient internal combustion engines using liquid fuels (either petroleum- or biomass-based), advanced battery materials and technologies including the testing of battery packs, and the technologies to support the successful introduction of fuel cell vehicles into the market.

Climate Security Program Area

The Climate Security program works to understand and prepare the nation for the national security implications of climate change.

Our nation's fundamental security requires not only military capability and infrastructure, but also stability and predictability in a host of other areas ranging from energy supply, communications, and financial markets to the nation's preparedness for natural disasters and long-term changes in our environment, such as shifts in climate. It is well documented in the geologic record that the Earth's climate is not stagnant but changes continually and sometimes abruptly. Abundant scientific data point to Earth's present-day warming, and the nation must be prepared to deal with specific consequences of an evolving climate. Sandia's many technical capabilities, including geosciences, modeling and simulation, technology development, and data analysis provide a means to assess the effects of climate change on our national security. The impacts may range from international instability, to the need for additional electricity for heating and cooling, to more frequent extreme weather events. Sandia's Climate Security program works to understand and help address the impacts of climate change on the nation.

Through a multipronged research approach, the Climate Security program seeks to

- improve our understanding of Earth's climate processes through more accurate, sensitive, and comprehensive sensing and monitoring;
- reduce GHG emissions by understanding their sources through coupled advanced measurement and analysis methods for climate treaty verification and policy support
- predict with greater accuracy and precision the possible outcomes of climate processes by applying that data to climate models with greater and greater resolution;
- quantitatively assess the uncertainties of socio-economic ramifications related to climate change;
- mitigate climate-change impacts by fostering scientifically sound, reliable, and economically reasonable next-generation technologies and processes for fossil-fuel energy generation and emission sequestration; and
- address water-scarcity issues that have been/ potentially will be brought about by climate-change processes, on both the domestic and international levels, to enhance security and stability.

CLIMATE SECURITY GOALS

1. Assess U.S. security impact risks by modeling climate and human response at the regional level with quantified uncertainty.

This goal is important to the Sandia program and the international research community because we still cannot predict how climate will behave at a fundamental level. We must reduce uncertainty, but a more efficient approach is to first quantify the uncertainty that exists. Uncertainty quantification (UQ) methodology works to identify "important" areas of uncertainty—where an uncertainty will cause the widest variability in the computational model's outcomes. As UQ researchers identify these factors, they can guide the climate science community to where their research efforts can be best applied to reduce overall system uncertainty.

Most climate-research scientists/programs focus on predicting the change in the global mean temperature. Sandia's Climate Security program focuses on answering, "What is the risk that the change will be greater than the expected mean change?" Our research effort explores how can society adapt to a larger-than-expected change in this parameter and understanding the national security implications of those required adaptations. Our program is developing concept models in computational simulation framework and systems models of the interactions between physical and social economic factors—working to predict/understand societal behavior in reaction to climate change scenarios.

Other Climate Security modeling efforts focus on the physics of climate change. We have developed a sophisticated atmospheric model—the most highly resolved global atmospheric model available, with a resolution of 1/8 of a degree or ~12.5 km per grid element. We developed the core algorithms and are running it at Sandia. We will provide this content to international process of assessing climate. It will be basis of future IPCC projections.

2. Develop and deploy monitoring, simulation, and analysis capabilities that position Sandia as a national leader in polar research.

Climate research has shown that changes are amplified in Arctic regions (2–3 times), in part because water undergoes a seasonal phase change there with large changes in albedo and energy absorption. These climatic changes are becoming highly significant from a national security perspective.

- ***Resource extraction***. As the Arctic becomes more accessible, many nations (those bordering the Arctic Ocean and others that do not) are preparing to engage in vigorous competition for the region's natural resources, previously deemed too difficult or expensive to extract.
- ***Ocean access***. As sea ice becomes less prevalent in the Arctic, the Arctic Ocean is more readily accessible for transportation by nonhardened vessels, significantly increasing the requirements for search, rescue, and emergency response.
- ***Security concerns***. A frontier that used to be secured largely by the difficulties of surmounting the challenges of a permanent ice pack is now being exposed to commercial activities—creating new operational requirements for the militaries of the nations who border the Arctic Ocean.
- ***Greenhouse gas emissions***. Increasing GHG and black carbon emissions are having more of an impact on the Arctic than on other areas of the world. Reducing these emissions

will require concerted efforts to reduce emissions globally, which will require a global climate treaty and effective policies designed to reduce emissions.

The sites that Sandia manages for the DOE on the North Slope of Alaska and adjacent Arctic Ocean provide our researchers with a rare window into the cloud and radiative processes that take place in Earth's atmosphere at high latitudes. This information is so desirable that the DOE Office of Science has allocated additional funding through its Office of Biological Environmental Research to (1) improve its Barrow, Alaska, facilities and (2) purchase equipment for another Atmoshperic Radiation Monitoring site at Oliktok Point.

Recently completed improvements include an automatic radiosonde balloon launching facility and an X-band radar at Barrow. Oliktok Point will host Doppler and high-spectral-resolution lidars, radar, and radiometers, along with meteorological equipment and other sensors. A hangar there also shelters unmanned aerial vehicles and tethered balloons, which will increase the scope of atmospheric data collection. These new measurement capabilities will provide more comprehensive data on clouds, aerosols, and visible and infrared radiation, while also monitoring sea ice conditions—improving the accuracy and reducing possible sources of error in climate models. We will host collaborators and scientific users who seek to take data from the Arctic atmosphere.

Our North Slope operations are also important operationally because we are now working to expand our climate/atmospheric research activities to include Antarctica. Our operational knowledge/experience from our North Slope research efforts will be a valuable asset as we explore partnership opportunities to expand to our climate research activities to the southern polar regions.

We have also established a measurement and modeling program to characterize GHG sources by emissions sector. These capabilities are targeted at climate treaty verification and policy support and will also be relevant to Arctic sensitivities to GHG and black carbon emissions.

3. Develop a technical approach for achieving DOE's goal of economical carbon capture, use, and sequestration, including $40/ton carbon capture.

The Climate Security program seeks to provide technology options to reduce/mitigate carbon's impact on the atmosphere by removing CO_2 from power generating plant emissions and industrial sites and keeping it out of the atmosphere for a very long time. Carbon capture and storage (CCS) technologies seek to capture emitted CO_2; compress it; and transport it to suitable permanent storage sites, such as deep underground.

Because industrialized societies produce such a great CO_2 emission volume to be captured, any significant remedy must be implemented on an industrial scale, i.e., it must be cheap. To date, a large CCS market has not developed, but CO_2 is a useful material for many other industrial processes. Reaching the $40/ton price mark will be sufficient to cover the cost of CCS activities and drive a viable business.

CCS is in a relatively early

phase of development, with several key questions remaining unanswered, including about its costs, timing, and relative attractiveness vs other carbon-lowering opportunities. Our researchers are investigating two major issues.

- Effective, economical carbon capture is a difficult engineering proposition with current technologies. How to "pluck" the molecule from an industrial emission stream and prepare it for the next step in the CCS process can be addressed through our materials science, systems engineering, and modeling and simulation capabilities.
- ECIS is also using its geotechnical and systems engineering expertise to examine the geology of sequestration. For example, a major use for CO_2 today is for enhanced oil recovery (EOR, CO_2 is injected into a reservoir to maintain pressure and improve oil displacement), but questions remain, i.e., will CO_2 used for EOR stay sequestered?

Sandia's resources and capabilities in basic research such as geoscience, material science, advanced simulation, probabilistic risk assessment, dynamic simulation, and at the Combustion Research Facility that, while developed for other purposes such as underground repositories, the NW program, and automobile efficiency research, can be applied to CCS problems.

4. Develop frontier fossil energy resources, such as shale gas and oil, through advanced resource characterization and production methods that mitigate environmental impacts.

In general, natural gas has approximately half of the carbon-emission footprint of coal. Recent breakthroughs in in exploration/extraction technologies (horizontal drilling and hydraulic fracturing) have made vast deposits accessible for economic energy production. Our Climate Security researchers will apply their geotechnical, modeling, and systems engineering expertise to understand the implications of this new resource for national energy independence and for the climate. We will initiate several systems studies to identify where we might have most impact, what's likely to evolve, and where we can contribute to advancing the environmentally responsible use of these vital energy resources.

5. Create a strategic approach to growing the water security program to a critical mass commensurate with the strategic significance of the issue.

Water is important to our domestic economy. In addition to its obvious uses in agriculture and the average citizen's everyday life, it is intimately related to the energy cycle. Its scarcity in the American west can limit energy generation and/or increase the cost significantly. Water scarcity is an issue internationally as well. Where water shortages exist, societal stability and security are often precarious.

Many programs throughout Sandia work to stabilize international relations and reduce conflict. Our Climate Security water research programs can work in a complementary fashion with these other efforts to promote stability and security around the globe.

A difficulty in this research area is that no single federal sponsor exists to coordinate water security studies. Leadership is fragmented, with portions existing in different federal entities as water resource issues impinge on their primary responsibilities. The Climate Security program is working to define a strategic approach to water security issues. To answer questions like, "How do we build a program?" "Who are significant stakeholders and how do we effectively engage with them?" Of primary interest to our program is an understanding of the dynamics between water and (domestic) energy production.

Infrastructure Security Program Area

The Infrastructure Security program develops and applies technologies and analytical approaches to secure the nation's critical infrastructure against natural or malicious disruption.

America's critical infrastructures provide the foundation for the nation's economic vitality, national security, and way of life. They frame citizens' daily lives and support one of the world's highest living standards. The systems, facilities, and functions that comprise these infrastructures are sophisticated, complex, and highly interdependent. They are comprised of physical, human, and cyber assets and have evolved over time to be economical and efficient systems. The increasing interconnections and complexity of these systems, subject to natural hazards and coupled with the new malicious threat environment, have created the need for a focus on interdependencies and the consequences they propagate.

A key objective of the Infrastructure Security program area is to support the preparedness and protection of our nation and society by providing analyses of the technical, economic, and national security implications of the loss or disruption of these critical infrastructures, and assist in the understanding and technology development of infrastructure protection and infrastructure disruption mitigation, response, and recovery options.

The nation's energy infrastructure, particularly electricity and hydrocarbon fuels, is of special interest because it faces two foundational challenges as we seek to forge a path toward an energy independent and secure future. First, elements of the infrastructure, such as the electricity T&D network, have not significantly changed since their initial creation over a century ago. It is clear that new approaches are required for the grid to accommodate the integration of intermittent renewable energy sources such as solar and wind. Second, the reliability and resilience of our energy distribution is central to our national security. For example, robust and secure electrical power is essential to domestic military installations.

The programs of the Infrastructure Security program area work to fully understand, sustain, improve, and where necessary revitalize, the interconnected network of energy delivery systems. Sandia's modeling and analysis capabilities allow us to understand the infrastructures' performance under unusual conditions, the effects of interdependencies, and the dynamics of their interconnections. To better understand the complexities of the interconnected infrastructures, we collaborate with private sector infrastructure experts to develop methodologies and tools for characterizing and simulating their performance.

America's energy infrastructure doesn't stop at its borders. A significant portion of the nation's liquid hydrocarbon fuels is imported from areas of the world subject to rapid social and political upheaval. This upheaval can jeopardize key facilities that process these fuels. This program area includes work addressing the protection of key fuel processing facilities and their supporting infrastructure by providing evaluation, physical protection training, and expert advice to the owners and operators of these international facilities.

As America's infrastructures have become more complex and interconnected, their operation and control has become more complicated. Automated control systems, called supervisory control and data acquisition systems, networked across the Internet have been widely deployed to operate these infrastructures. These systems, and the Internet over which they handle information, are an identified security vulnerability for the infrastructures they control. The Infrastructure Security program area works with several government agencies in the area of cybersecurity to ensure the integrity and availability of the nation's cyber infrastructure.

The performance of the nation's infrastructure is an essential component of the nation's economic prosperity. Through its programs and projects, the Infrastructure Security Program Area seeks to endow the infrastructure with five characteristics: security, reliability, safety, sustainability, and cost effectiveness.

INFRASTRUCTURE SECURITY GOALS

1. Increase the resilience of U.S. and key global critical infrastructure systems by providing increased understanding of interdependencies and risk.

America's continuing economic prosperity depends on its infrastructure. But more than that, in a modern society, where just-in-time delivery applies not only to manufacturing and industry but to energy and food supplies as well, our urban population's very survival also depends on critical infrastructures. Infrastructure disruption can come from many causes—some natural, some accidental, and some that are maliciously intentional. Hurricane Katrina showed us how the disruption of the gulf-states petroleum infrastructure has national repercussions. The September 11th attacks were essentially localized, but have had acute and long-term effects on a national and international scale. When the Interstate 35W bridge collapsed in Minneapolis, it took three months to clear the debris from the Mississippi. If that collapse had happened on the lower Mississippi, the disruption of barge traffic up and down the river could have had similar national consequences. America has endured these disruptions before and will again.

Critical infrastructure, infrastructure whose disruption will put many lives at risk, suffers not only under the threat of direct interruption but also from disruption via the interruption of another element of the infrastructure on which it depends. The nation must be prepared for disruption to its critical infrastructure—and in order to do this, we must understand the interdependencies between the infrastructure's disparate systems. We must understand if some systems are more at risk than others and why. We need to know if evolving interdependencies increase or change the risks to critical systems. Are the trends toward more vulnerable conditions/configurations? Or less? How will critical infrastructure disruptions impact national security?

Understanding the linked, interdependent nature of the nation's critical infrastructure in order to enhance preparedness, protection, response, recovery, and mitigation is a hard problem—one that requires the capabilities of a national laboratory. It is through high-performance computing (HPC) modeling and analysis that Sandia can quantify and qualify the interactions of political, health, social, economic, and technical systems. Simulation can couple the effects of socioeconomic systems (power networks, distribution systems, transportation links) to physical systems (climate, weather, geology, geography) to understand large, complex data sets and capture nonlocal, nonintuitive interdependency effects at multiple simultaneous scales and resolutions. By studying these infrastructure systems and their effects on each other in simulation, we can advise policy makers and industry stakeholders on how to mitigate disruption effects and build resiliency into the national system.

2. Grow critical cyber security capabilities within DHS with Sandia as the enduring development partner.

The Department of Homeland Security (DHS) has the mission of protecting civilian federal government information networks against a full range of threats. Government networks and servers are repositories of vast amounts of information that, if stolen, could compromise Americans' physical safety and security as well as their privacy and financial security. As the U.S. benefits from the past few decades' technological advances, we increase our dependence on interconnected devices and systems. This dependence creates vulnerabilities, which might be exploited by adversaries ranging from criminal organizations through nation states. The complexity of these interconnected systems and the rate of technological change cries out for a national-lab-level approach to mitigate the risks to our government systems and our critical computer infrastructures.

Sandia's goal is to develop game-changing cybersecurity capabilities to support DHS's mission of securing the nation's ".gov" domain and defending critical infrastructures (e.g., the electric grid and other energy infrastructure) from cyber-based vulnerabilities. We will evaluate systems with the potential to impact critical infrastructures for supply-chain vulnerabilities and create mitigation strategies for supply-chain-induced risks. We will devise strategies to extend cybersecurity beyond government assets to the telecommunications providers, industry partners and subcontractors, and to global partners. Lastly, we will develop a scalable process to assess and improve the cybersecurity performance of government agencies and critical infrastructures, with the objective of providing agencies a mechanism for sharing threat, compromise, and mitigation data. Our goal is to build/use a threat model in order to guide development, acquisition, and operation of a protective system. The complexity and scale of this system will be unprecedented; it must scale over a wide range of attributes: network size, data sensitivity, communications capacity, geographical distribution, and operational authorities. Sandia is contributing to the solution by providing architectural designs based on threat models. We are providing much needed scalability to the efforts to address the cyber risks. We are tackling the big problems, like the supply-chain risk, which are so challenging as to be largely deferred by the other contributors to cybersecurity.

Sandia is partnering with the University of Vermont and an array of Vermont stakeholders (utility companies, private industry, residential and industrial consumers, policymakers, and regulators) to create a test bed of the nation's first statewide, 21st century energy infrastructure. This Vermont initiative will require innovation in a broad spectrum of areas including Sandia's cybersecurity competencies.

3. Establish at Sandia and DHS the capability (people, processes, and tools) to bring physical and cyber risks under a common risk-management framework.

The last couple years have brought increased recognition of the impact of the cyber threat to the nation's critical infrastructure. The Department of Homeland Security has the responsibility to address this cyber-physical connection. Sandia has established programs and relationships with the two key DHS entities in this domain: the Office of Cybersecurity and Communications (CS&C) and the Office of Infrastructure Protection (IP).

Recently, CS&C and IP established two pilot projects with the goals of (1) providing actionable information to critical infrastructure owner/operators and state and local governments, and (2) getting the cyber and physical infrastructure experts to work jointly toward a common outcome.

The execution of these pilots highlighted the need for a common risk approach to evaluate the nexus of cyber and physical threats. Furthermore, the pilots highlighted the critical importance of developing human capital capable of simultaneously addressing cyber and physical threats.

There is also new Administration guidance to transform Infrastructure Protection into Infrastructure Resilience. This will require an evolution of the existing "risk frameworks" into a "risk-informed resilience" framework.

These transitions provide an important opportunity for Sandia to increase its impact. Sandia has established a reputation with DHS as a thought leader on infrastructure resilience. The Infrastructure Security program's goal is to develop a common "language" between the physical and cyber domains: appropriate norms, reference values, and common framework that allow customers to perform tradeoffs between the risks incurred in either the cyber or the physical space. To do this, the Infrastructure Security program is following a two-pronged approach

1. engaging with senior leadership at DHS National Protection and Programs Directorate, CS&C, and IP, providing information about capabilities and gaps, and making recommendations and

2. developing a

comprehensive Sandia internal approach that connects and develops our expertise in cyber, physical infrastructures, risk, and resilience.

Sandia has a golden opportunity to exemplify the new priorities. At times, Sandia's current programs and activities have mirrored the divisions between its various sponsors. This Infrastructure Security goal specifically addresses the increased national impact that Sandia can have by integrating internally. Furthermore, it recognizes that the new capability should not reside just at Sandia, and that Sandia must work with its DHS partners to deploy and engrain it in their ability to deliver their new mission.

4. Develop and implement a comprehensive Sandia program to support the modernization of the U.S. electric grid, with a focus on security and resiliency.

Our nation's energy infrastructure faces two foundational challenges as we seek our vision toward an energy independent and secure future. First, the electricity T&D networks have not significantly changed since their initial creation over a century ago. It is clear that new approaches are required for the grid to accommodate the integration of intermittent renewable energy sources such as solar and wind. Second, the reliability and resilience of our grid is central to our economic and national security. Robust and secure power is essential to key infrastructures that support our national defense and economy. Electricity outages presently cost our economy over $150B annually.

Modernizing our electrical grid is a tremendous undertaking, requiring the coordination and collaboration of a wide range of stakeholders spanning federal and local governments, the energy industry, electric utilities and—perhaps most importantly—the myriad of consumers.

The American Recovery and Reinvestment Act (ARRA) program in 2009 made an initial and significant step toward grid modernization. Over $10B of investment was made in smart-grid build outs. Those investments are rapidly being implemented, and there is now a great opportunity to build on the ARRA program toward true grid modernization.

Sandia supports the DOE, DHS, and DoD efforts to modernize the electric grid by providing R&D of new transformational energy technologies; analyses of the technical, economic, and national security implications of the loss or disruption of critical civilian and military energy infrastructures; and assisting in the understanding and technology development of infrastructure protection and infrastructure disruption mitigation, response, and recovery options.

5. Develop end-user relationships to accelerate infrastructure and cyber solutions for security and resiliency.

Infrastructure- and cyber-related problems are so complex that solutions will require unprecedented collaboration between governmental, regulatory, and industry stakeholders. As a federally funded R&D center, Sandia is uniquely positioned to work collaboratively with key policy makers, while protecting the proprietary interests of infrastructure owners/operators. The Infrastructure Security program has an important opportunity to enable holistic infrastructure security and resilience through industry engagement. The Infrastructure Security program can achieve widespread impact from its work through industry partners, as infrastructure owners/operators deliver secure and resilient solutions to the nation's critical infrastructures through their products and consumer networks.

Through partnerships, Sandia provides expertise and technology to meet industrial needs. By applying Infrastructure Security program capabilities to industrial problems, Sandia gains new perspectives on national infrastructure and cyber issues; and industry can market more robust, new, and/or improved products. This benefits ECIS as well as other Sandia national security mission applications. Industry partnerships are also the primary mechanism for commercializing Infrastructure Security program technologies in meeting mission sponsors' expectations.

Industrial partnerships in the Infrastructure Security program can range from collaborating on basic R&D to commercializing mature technologies. In some cases, infrastructure owners/operators come to Sandia with well-defined needs, for which the Infrastructure Security program can provide discrete access to existing technologies and capabilities (examples of current and emergent opportunities, which are not Unclassified Unlimited Release, might include: utilities and Independent system operators, Coca-Cola, Northrop Grumman, Boeing, Heinz, Archer Daniels Midland, etc.). In other cases, Sandia participates in industry and regional cross-sector coalitions (e.g., DHS Sector Coordinating Councils, Bay Area Science & Innovation Consortium) to gain a better understanding of existing and imminent infrastructure challenges. With an intimate understanding of key infrastructure challenges, Sandia can partner directly with infrastructure owners/operators, or work with risk analysis providers, to improve knowledge and tools (e.g., cooperative R&D agreement with Aon, CRISTAL/FASCAT). Finally, Sandia also works through its government partners to test and validate commercial solutions (e.g., DHS S&T Cyber Transition to Practice).

The importance of industrial partnerships to the Infrastructure Security mission is reflected in the ECIS ten-year objective to: "Accelerate U.S. industry's innovation, development, and successful deployment of energy solutions to the nation's most challenging problems through seamless integrations of Sandia's science, engineering, and security expertise by leveraging and integrating across our U.S. government-sponsored programs and relationships and by partnering with industry academia and other labs."

Enabling Capabilities Program Area

The Enabling Capabilities program area provides a differentiating science understanding that supports ECIS SMU and Sandia National Laboratories mission technologies now and into the future.

Enabling Capabilities is unique among ECIS' four program areas. The other three areas each focus on one (albeit large) research area to bring Sandia's research and engineering capabilities to bear on the problem and help the nation forge a solution. The Enabling Capabilities program area is organized to cut across the ECIS areas with a capability base to support all ECIS goals as well as provide a science base, which supports and integrates with other SMUs. The scientists and engineers in the Discovery Science and Engineering activity pursue fundamental research that has applications in multiple program areas. Because Enabling Capabilities has connections interwoven throughout Sandia, this discovery science can easily find more than one application.

Enabling Capabilities also pushes to rapidly advance connectivity of scientific breakthroughs to real-world applications delivered by industry. Congress established an Advanced Research Projects Agency—Energy (ARPA-E) within the DOE to be a catalyst for transformation, and to do so with fierce urgency. Our nation's history is replete with examples of pioneers and entrepreneurs who took risks. These innovators often failed initially, but quickly learned from those failures, competed against each other, and innovated in both technology and business to create the largest industrial base the world has ever seen. ARPA-E's goal is to tap into this truly American ethos, and to identify and support the pioneers of the future. With the best R&D infrastructure in the world, a thriving innovation ecosystem in business and entrepreneurship, and a generation of youth that is willing to engage with fearless intensity, we have all the ingredients necessary for future success. The ECIS ARPA-E activity is tasked with working with the scientists and engineers of the ECIS program areas to form partnerships with industry, academia, and entrepreneurs to develop research proposals that will win grant awards from ARPA-E.

The Laboratory Directed Research and Development (LDRD) program at Sandia has invested a portion of the program on low-to-midscale technology readiness levels that advance our understanding and capabilities to solve problems in the nation's energy, climate, and infrastructure security sectors. Enabling Capabilities has the responsibility to lead this portion of the LDRD program for the ECIS SMU—the ECIS LDRD Investment Area—and this forms the third focus area in the Enabling Capabilities program area.

The final focus area in Enabling Capabilities recognizes the importance of policy decisions and government regulations—and how these impact our nation's security. As a national laboratory, Sandia has the responsibility to bring its capabilities to bear as a resource to help decision makers craft the strategies and policies. In many cases, we are required to advance the current state of capabilities in order to address the most challenging questions being debated. Further, we have the responsibility to use our analysis capabilities to examine a systems view—weaving together interconnected activities that are complex and adapting to their environment, whether it be man-made or deriving from nature. The Systems Analysis and Policy activity takes a complex, adaptive system-of-systems approach to forge meeting points between research efforts in the ECIS SMU and throughout the nation's energy, climate, and infrastructure research enterprise to foster a larger view among the participants.

ENABLING CAPABILITIES GOALS

1. Nurture discovery science for fundamental breakthroughs and deepen our competencies

in key strategic areas that enable ECIS mission objectives and goals.

Our nation faces serious, looming challenges in the areas of energy, climate, and infrastructure security, on which this document has focused. The ECIS SMU scientists and engineers apply their expertise to the challenges described at the beginning of this strategic plan. However, focused, applied research and analysis can only bring us so far. Many of the challenges cannot be solved with improvements to current technologies or extrapolations from them—they require discovery and an understanding of the foundational characteristics of materials, energy, and their interactions.

The Enabling Capabilities program area supports this kind of foundational research at facilities such as the

- Center of Integrated Nanotechnologies (CINT),
- Microsystems Engineering, Science, and Applications (MESA) facility,
- CRF (Combustion Research Facility),
- Ion Beam Laboratory,
- Processing and Environmental Technology Laboratory,
- Computer Science Research Institute, and
- Integrated Materials Research Laboratory.

With these facilities, Sandia has extensive, in some cases unique, state-of-the-art laboratory facilities for understanding mathematics, algorithms, and software codes; material growth; fabricating microsystems; semiconductor processing; and characterizing structural, electronic, and optical materials. The combination of facilities is unparalleled anywhere in the world. In addition to special lab facilities and equipment, we have cultivated substantial personnel expertise, in parallel, over decades, in a broad range of mathematics and physical science, chemistry, materials science, and engineering disciplines. This collection of expertise—that can be brought together into large, comprehensive teams—is very rare.

It is through the use of these facilities by our collection of unique scientific and engineering capabilities that we can understand and develop the foundational scientific principles of novel materials and processes into the technology of tomorrow that can surmount the challenges that we face in energy, climate, and infrastructure protection that can secure and sustain our nation.

In all of the Enabling Capabilities efforts, we seek out collaborative partnerships with other institutions in order to better leverage all available capabilities. A shining example of this collaborative spirit is CINT, which we cohost with LANL. Sandia will continue to nurture and grow this relationship and expand CINT's impact on Sandia's mission areas and our partnerships with industry. Another area in which Sandia can nurture and support discovery science is in our extensive HPC capacity that brings closer together in co-design the architecture of the computing machine with the ECIS problem to be solved. Sandia seeks to expand the role and impact of HPC into a wider range of DOE/Sandia mission areas (energy, climate, and infrastructure assurance) that position Sandia in a leadership role for the DOE complex in exascale planning and execution that is integrated across both Advanced Scientific Computing Research and Advanced

Scientific Computing programs.

2. Accelerate industry development of transformational energy technologies through ARPA-E.

The widespread use of fossil fuels has long driven the engine of economic growth and, consequently, has significant national security implications. Looking toward the future, the nation that successfully grows its economy with more efficient energy use, a clean domestic energy supply, and a smart energy infrastructure will lead the global economy of the 21st century. ARPA-E was created within DOE to be a catalyst for such a transformation, and to do so with fierce urgency. ARPA-E has rapidly created a portfolio of transformative R&D projects targeted to address the nation's technological gaps and create new paradigms for energy sector solutions. Sandia can help accelerate innovation by engaging current and future ARPA-E innovators that otherwise might not benefit from our intellectual resources and relevant capabilities. Our strategy involves three simultaneous approaches:

- build relationships with current ARPA-E investigators on projects where we can add value;
- explore partnerships with innovators in the group of highly-ranked but unfunded ARPA-E proposals to pursue scientifically sound, high-risk R&D of keen interest to ARPA-E; and
- contribute technical leadership to ARPA-E to shape future directions as this agency becomes established within DOE.

3. Pioneer advanced electrical energy storage technologies and develop new technologies for enhanced battery safety and reliability, through scientific research in materials and chemistry, and innovative architectures and cell designs.

We perform R&D that creates options for advancing electrochemical energy storage in stationary and transportation applications. A particular Sandia strength is the capability base to assure reliability and safety of components and systems. This capability draws upon deep scientific roots in the integration of theory, experimentation, modeling, and analysis. In order to expand our impact we seek and support partnerships from across the customer program areas, with other national labs, academia, and industry. An example of such a partnership is the Joint Center for Energy Storage Research (JCESR) which is a DOE Hub led by Argonne National Laboratory. A focus of this goal is to advance our understanding of materials performance in batteries such that we can determine quantitative performance of multiple battery technologies sufficiently to predict their failure mechanisms, lifetimes, and new design principles for future battery options that operate in stressing environments.

4 Enable analysis capabilities to inform and influence the nation's debate on energy strategy and policy.

The ECIS LDRD investment area focuses on R&D that advances our capability base and creates a differentiating expertise that we bring to the nation. One important focus in the LDRD portfolio of work creates advanced systems analysis capabilities for the ECIS SMU and demonstrates that advancement through use. We build upon this capability base to perform analyses that allow us to engage strategic decision makers at the national and state levels. The decision makers either influence debate about energy, climate, and infrastructure policy or are actively creating that policy. A goal of Sandia National Laboratories is to become a visible national presence and a resource for energy policy decision makers. We seek to be recognized for providing the context for energy strategy and policy decisions in terms of technology options as well as tradeoffs in policy options.

ECIS SMU Key Facilities

Many of Sandia's unique research facilities are available for use by industry, universities, academia, other laboratories, state and local governments, and the scientific community in general. User and collaborative facilities are a unique set of scientific research capabilities and resources whose primary function is to satisfy DOE programmatic needs, while also being accessible to outside users.

The National Solar Thermal Test Facility (NSTTF), a DOE Office of Energy Efficiency and Renewable Energy (EERE) sponsored facility, provides energy researchers with experimental engineering data for the design, construction, and operation of unique components and systems in proposed solar thermal electrical plants.

The Joint BioEnergy Institute (JBEI) is a DOE SC -sponsored San Francisco Bay Area scientific partnership with a mission to advance the development of the next generation of biofuels—liquid fuels derived from the solar energy stored in lignocellulosic (nonfood) plant biomass.

The Combustion Research Facility (CRF) is an internationally recognized DOE SC-sponsored collaborative research facility aimed at improving our nation's ability to use and control combustion processes.

Sandia's Battery Abuse Testing Laboratory (BATLab) is a DOE EERE-sponsored facility at the forefront of testing the limits of what batteries can safely handle and provides critical data for ensuring the safety and reliability of the next generation of batteries.

The National Infrastructure Simulation and Analysis Center (NISAC) is a DHS-sponsored modeling, simulation, and analysis program that provides strategic, multidisciplinary analyses of critical infrastructure and key resource interdependencies and the consequences of disruptions at national, regional, and local levels.

The Photovoltaic Systems Evaluation Laboratory (PSEL) is a multiuser, multi-sponsor facility that supports research in PV cells, modules, and arrays—allowing detailed, comprehensive analysis in PV systems design, optimization, and characterization in real-world scenarios. PSEL conducts research on behalf of the DOE, DoD, and other customers, often in collaboration with industry/academic partners.

The National Supervisory Control and Data Acquisition (SCADA) Test Bed is a DOE Office of Electricity Delivery and Energy Reliability-sponsored resource that combines state-of-the-art operational system testing facilities with research, development, and training to discover and address critical security vulnerabilities and threats to the energy sector.

The Center for Integrated Nanotechnologies (CINT) is a DOE SC-sponsored user facility that supports researchers working to determine the scientific principles that govern the design, performance, and integration of nanoscale materials. CINT's emphasis is on exploring the path from scientific discovery to the integration of nanostructures into the micro and macro worlds.

The Distributed Energy Technologies Laboratory (DETL) is a DOE EERE-sponsored facility that supports research with industry/academic partners to integrate emerging energy technologies into new and existing electricity infrastructures to achieve a reliable, low-carbon electric infrastructure.

The Scaled Wind Farm Technology (SWiFT) Facility, hosted at Texas Tech University, is a DOE-EERE-sponsored, recently initiated facility which is being developed to reduce power losses and damage caused by turbine–turbine interaction; enhance energy capture and damage-mitigation potential of advanced rotors; and improve the validity of aerodynamic, aero-elastic and aero-acoustic simulations used to develop innovative technologies.

The Atmospheric Radiation Monitoring (ARM) Climate Research Facility is an Office of Biological and Environmental Research (BER) user facility within DOE's Office of Science providing the climate researchers with strategically located in situ and remote-sensing observatories on Alaska's North Slope that provide data on clouds, aerosols, and visible and infrared radiation.

The PV Regional Test Center (RTC) at Sandia's NSTTF site, funded by DOE EERE, independently validates 30–300 kW PV system performance and reliability for emerging U.S. manufacturers and develops standardized processes for PV system monitoring/validation—to assure banks, insurance companies, and other stakeholders that new PV technologies will work with high fidelity and robustness over time and meet contractual obligations.

Sandia's Technical Area III test capabilities include high-speed sled tracks; a cable pull-down system; fire and thermal radiation testing capabilities; centrifuges and high-shock linear actuators; and explosives testing areas to asses structural, mechanical, electrical system performance and damage analysis under harsh environments. The large-scale liquefied natural gas (LNG) fire and cryogenic damage testing research was conducted in Tech Area III.

The Thermal Test Complex evaluates thermal loads from fire environments and the multi-physics response of hardware subject to fires. Funded by the DOE Nuclear Weapons (NW) program, laser diagnostic equipment is used to help understand the burning process. Systems to allow jet fuel, methanol, and other liquid fuels as well as hydrogen, methane, and other gas fuels are part of the facility's design.

Sandia's Aerial Cable Facility provides a unique capability to precisely simulate a wide variety of environments in a highly instrumented test arena. The DOE NW-funded facility has four primary cable systems that span two ridges over a mountain canyon.

The Rocket Sled Track Facility provides a controlled environment for high-velocity impact, aerodynamic, acceleration, and related testing. The DOE NW-funded facility uses photometrics, laser trackers, and telemetry and hardwire data-gathering systems. The combination of ingenuity, experience, and instrumentation available at this facility makes it unique for research, test, and evaluation purposes.

ECIS SMU Leadership of Federal Energy Research Efforts

Concentrated Solar Power

The DOE EERE's Solar Energy Technologies Program Concentrated Solar Power (CSP) subprogram works to lower costs and advance technology to the point that CSP is competitive in the intermediate power market by 2015–2017 and in the baseload power market by 2020–2022. Sandia and the National Renewable Energy Laboratory manage the R&D support for the U.S. CSP industry with critical research to meet cost, reliability, performance, and manufacturability challenges.

Energy Frontier Research Center for Solid-State Lighting Science

Solid-state lighting (SSL) is an emerging technology with the potential to reduce that energy consumption by a factor of 3–6 times. Despite a decade's enormous progress, however, SSL remains a factor of 5–10 times away from this potential. Sandia's Solid-State Lighting Science a DOE SC Energy Frontier Research Center will accelerate advances in this fundamental science by exploring energy conversion in tailored photonic structures.

Energy Storage Systems

The Sandia managed DOE Energy Storage Systems program studies integrated electrical storage systems and power sources: materials, engineering, and testing (including power electronics and controls), especially as storage technologies relate to electric utilities, renewables, and grid security.

National Infrastructure Simulation and Analysis Center

Physical, human, and cyber assets make up key resources and critical infrastructures. NISAC's infrastructure modeling and analysis, decision support tools, and knowledge management support our nation's preparedness by providing analyses of the technical, economic, and national security implications of the loss or disruption of critical infrastructure; NISAC activities assist in understanding infrastructure protection, mitigation, response, and recovery options.

Ocean Energy

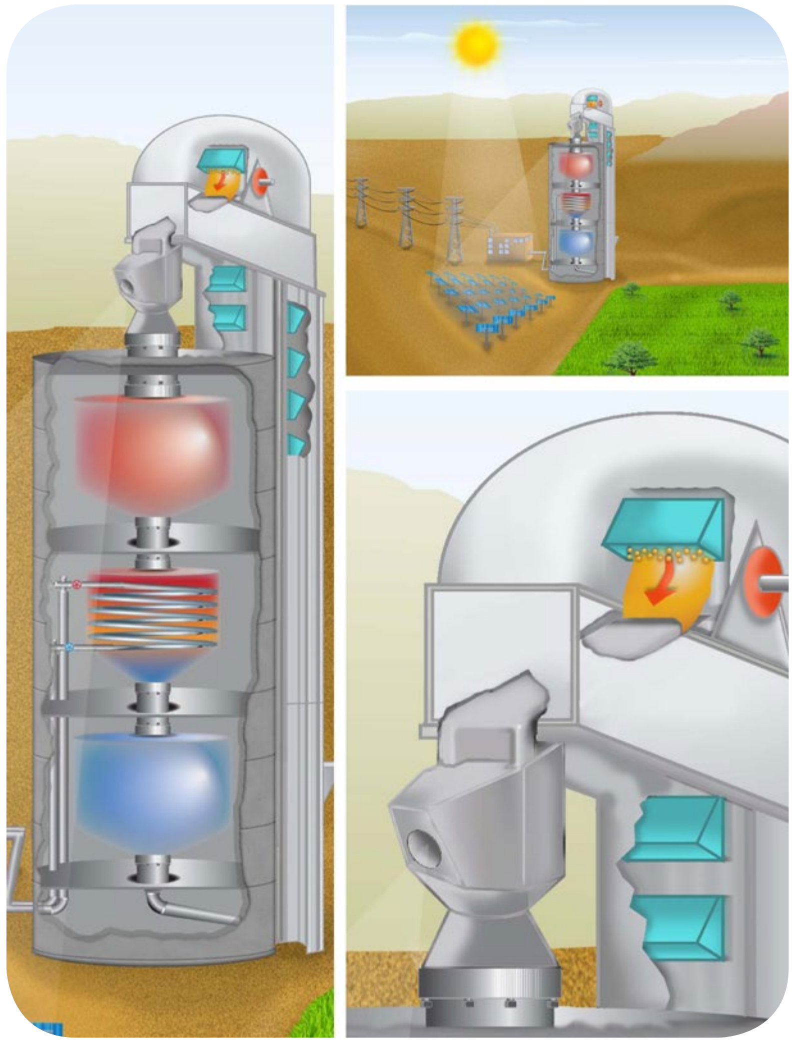
The DOE's Water Power Program supports the development of advanced water power devices that capture energy from waves, tides, ocean currents, rivers, streams, and ocean thermal gradients. Sandia, through a partnership with several national laboratories and academic institutions, leads two of the four topic areas awarded under a $9M grant and will provide technical support in a third topic area.

Smart Power Infrastructure Demonstration for Energy Reliability and Security Joint Capabilities Technology Demonstration

The SPIDERS JCTD—a combined agency (DOE, DoD, DHS) demonstration effort for energy security at military installations—combines several DOE efforts: smart grid, cyber security, energy efficiency, renewable energy, and energy storage via demonstration and early deployment. Sandia is the lead systems engineering lab (among five overall DOE labs), and is providing the Deputy Technical Manager for the project.

Strategic Petroleum Reserve

Sandia is the technical leader for geology, geomechanics, and computational modeling issues related to the Strategic Petroleum Reserve (the largest stockpile of government-owned emergency crude oil in the world), which stores crude oil in solution-mined salt domes as a national response option should a disruption in commercial oil supplies threaten the U.S. economy and as a national defense fuel reserve.



Top: An artists' rendering of the falling-particle receiver concept under investigation at Sandia. When perfected, this system will enable CSP plants to provide power long after the sun has stopped shining for the day.

Bottom: Two views of Sandia's Molten Salt Test Loop (MSTL), which will allow Sandia researchers to assist industry in perfecting thermal energy storage systems for concentatated solar power (CSP) generation.

Our History

Sandia & the Nation's Energy Challenges

Sandia was born as a nuclear weapons (NW) engineering laboratory, a place with deep strengths in science and engineering to support complex systems solutions.

Long-standing competencies in areas such as materials at extreme conditions, large-scale test, engineering design simulation, systems reliability, and risk assessment proved to be invaluable to broader national security challenges beginning in the 1960s. It is Sandia's national security mission that brought energy science and engineering into the labs. Just as no nation can ensure its security without a means to defend itself, no nation can survive without an adequate supply of safe, assured, affordable, and environmentally sound forms of energy.

The energy crisis of the 1970s spawned significant and continuing Sandia energy programs. These programs benefitted from enduring support by Sandia's technical base in areas that were relevant to the nation's energy challenges, while also strengthening our core NW expertise.

Nuclear Energy

In the 1970s and 1980s, Sandia scientists and engineers supported the Nuclear Regulatory Commission (NRC) by providing independent technical expertise in nuclear reactor safety and reliability. In the 1990s and 2000s, the NRC and Department of Energy (DOE) Offices of Nuclear Energy and Naval Reactors continued to expand our core capabilities especially in the area of probabilistic risk assessment, computer simulation, and environmental testing.

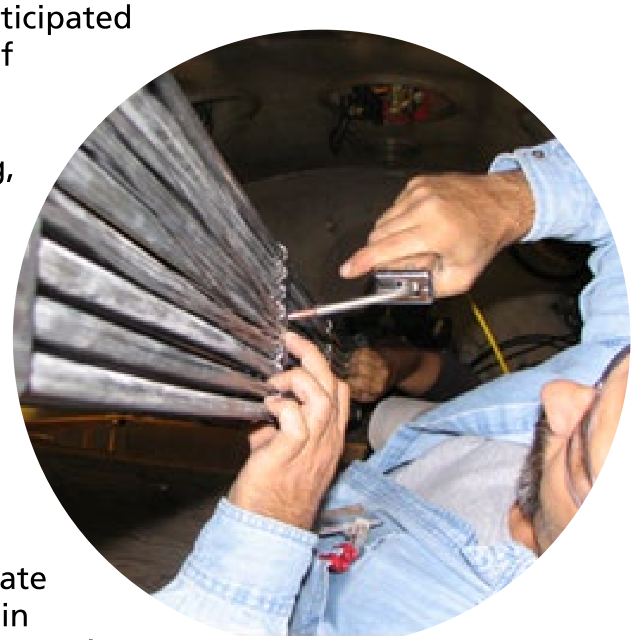
Over 30 years of research into severe accident phenomenology, spurred by the Three Mile Island accident of 1979, has led to the development of the modern risk informed regulatory framework in place today. Sandia has played a principal role in many of the regulatory research efforts. For example, MELCOR (Methods for Estimation of Leakages and Consequences of Releases) was developed in 1989 as a fully integrated, engineering level code to model severe accident progression in light water reactor power plants. MELCOR is being applied today as a key element of the U.S. support to the Fukushima reactor crisis in Japan.

Renewable Energy

Wind energy programs at Sandia began in the early 1970s, leveraging our world-leading expertise in systems analysis and integration from our NW programs. Our initial activities were aimed at modernizing the eggbeater-shaped vertical-axis wind turbine (VAWT) invented by G.J.M. Darrieus in the 1920s. Complex computer codes were developed to accurately simulate the performance of a variety of blade configurations in a wide range of wind conditions and to predict their fatigue life. Advanced materials were applied to improve reliability. In return, the wind analyses activities stimulated advances in mathematical modeling that later found benefit in the NW program, bringing this synergistic relationship full circle.

The VAWT concept showed early promise, but horizontal-axis turbines were easier to enlarge for utility-scale generation. Recently, Sandia renewed its VAWT research for offshore applications.

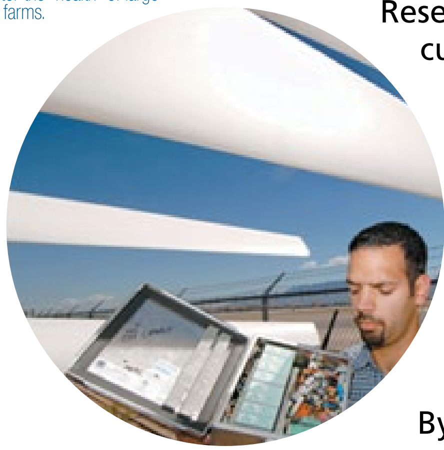
From these early beginnings, Sandia has continued to make major contributions to the state-of-the-art in wind turbine technology. Our scientists have continued to conduct applied research to improve wind turbine performance, reliability, and reduce the cost of energy. Sandia has participated in all aspects of wind-turbine blade design, manufacturing, large-scale testing, and system reliability. By partnering with universities and industry, Sandia has worked to advance the state of knowledge in the areas of materials,



Sandia researchers prepare a mock-up of a spent nuclear fuel rod bundle for testing.

structurally efficient airfoil designs, active-flow aerodynamic control, and sensors.

The ATLAS II technology can monitor the "health" of large wind farms.



Researchers at Sandia are currently investigating integrated blade designs where airfoil choice, blade planform, materials, manufacturing process, and embedded controls are all considered in a system perspective. By collaborating with operators, developers, and manufacturers, Sandia evaluates known reliability problems and develops tools and methods to anticipate and investigate future reliability issues. From these collaborations, Sandia developed the Accurate Time-Linked data Acquisition System (ATLAS II) to monitor and record total system performance. The system provides data to help researchers and operators understand how turbine blade designs perform in real-world conditions, facilitating improvements on blade designs and our design codes.

Sandia's efforts in solar energy research began in 1972 in similar fashion to the area of wind energy. Existing expertise in systems analysis and engineering along with our long-standing experience in large scale testing were applied to improving concentrated solar technologies. Ever since that time, Sandia has played a key role in developing concentrated solar technologies for commercial power-plant use—technologies that involve collecting and focusing solar energy onto a receiver for conversion to other forms of energy. In each case, the goal is to heat a fluid (water, gas, or molten salt) and use that energy for driving a turbine/generator and/or for space-heating or other industrial purposes. Sandia has established baseline data on the performance of both traditional and innovative line concentrators (parabolic troughs), point concentrators (parabolic dishes), and heliostats for concentrating sunlight on tower-based receivers. We have also had responsibility for the materials-science work and computer codes that make these advanced designs possible.

In the mid-1980s, Sandia assisted in the engineering development of the nation's largest electricity-producing solar plant at that time, Solar One, near Barstow, California, which operated successfully from 1982 to 1986. To improve efficiency, Sandia led an effort to develop molten salt technology for energy storage. This enabled a recommissioned Solar Two in 1996. This facility produced steam to drive a turbine/generator that produced enough electricity for 5000 homes. The system was operated into 1999 and proved itself capable of operating smoothly through intermittent clouds and continued generating electricity long into the night.

Our competency in concentrated solar power (CSP) then expanded to the area of dish-Stirling engines. This concept links a parabolic dish reflector with the externally heated Stirling engine. Sandia began by studying the basic thermodynamics to evaluate the prospects for commercialization. For distributed receiver systems, then-current system analyses were a combination of simple models and detailed questions about the day-to-day performance of components. The models were refined as components arrived for testing.

In central receiver technology, Sandia developed more-complete mathematical models of plants based on operating experience at Sandia's Central Receiver Test Facility (Solar Tower, established in the late 70s) and at Solar One. These models simulate operation of a plant and determine its power output under varying conditions, allowing utilities to predict outcomes using different subsystem components. It also helps researchers direct efforts at improving key design areas to meet overall system goals.

Sandia's Solar Tower, parabolic trough, and dish-Stirling facilities were combined in the late 1970s into the National Solar Thermal Test Facility (NSTTF). Operated by Sandia for the DOE, the NSTTF is the only test facility of this type in the U.S. NSTTF's primary goal is to provide fully instrumented test facilities that furnish researchers with experimental engineering data for the design, construction, and operation of unique components and systems in proposed solar thermal electrical plants planned for large-scale power generation. In addition the facility can provide: high heat flux and temperatures for materials testing or aerodynamic heating simulation; large fields of optics for astronomical observations or satellite calibrations; a solar furnace; and a rotating platform for parabolic trough evaluation.

Top right: A parabolic trough concentrator with a black chrome receiver.

Bottom right: The Sandia solar tower has been a mainstay solar research facility for nearly 30 years.

Many aspects of the solar technology developed at Sandia more than thirty years ago are being commercially deployed. The Andasol generating station, located in central southern Spain, is a parabolic-trough style plant that employs molten-salt storage—enabling it to provide full generating power 7.5 hours after the sun has set.[1] Andasol 1 went online in March 2009. Andasol 2 has started the commissioning phase, and Andasol 3 is currently under construction.[1] Our technologies will also be integrated into the Ivanpah Solar Electric Generating System, located in the Mojave Desert. Ivanpah is planned to have a capacity of 392 MW, making it the world's largest solar thermal power project currently under construction.[2] Final approval was gained in October 2010. The first phase of the Ivanpah facility is scheduled to be finished in 2013.[2] Complementary work now going on at Sandia and elsewhere could also result in transportable fuels and chemicals from solar thermal technology.

Another progeny of Sandia's decades-long solar energy research program is the parabolic dish/Stirling engine system called the SunCatcher™. Stirling Energy Systems (SES) of Phoenix, Arizona, developed this system in partnership with Sandia. The SunCatcher systems holds the world's record for solar-to-grid efficiency (31¼%) and has a full year sunrise-to-sunset efficiency of ~25%—double that of other solar power systems.

An early version of the dish-Stirling concept used many small cast parabolic mirrors.

Sandia-SES development and testing activities led to significant performance improvement and operating-cost reduction. Sandia benefitted tremendously from its partnership with SES through access to operating systems, by developing optical tools and controls algorithms, and through many other activities that have all subsequently supported numerous solar projects.

Electric Grid Infrastructure

One of the critical issues with "alternative" power generation is integrating that power into the local utility's network and, ultimately, into the national power grid. During the 1980s, Sandia initiated the Distributed Energy Technology Laboratory to integrate emerging energy technologies into new and existing electricity infrastructures. Sandia's research spans generation, storage, and load management at the component and systems levels and examines advanced materials, controls, and communications to achieve the Lab's vision of a reliable, low-carbon electric infrastructure.

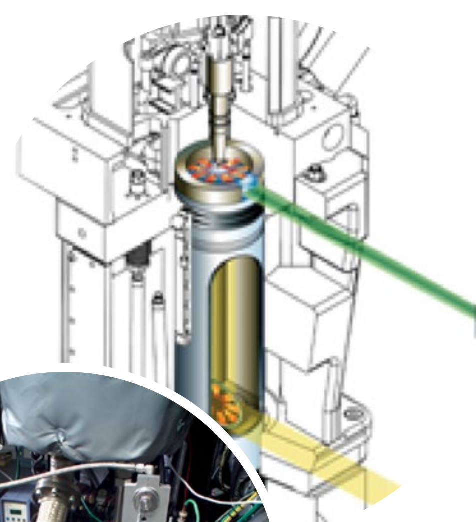
Combustion Science

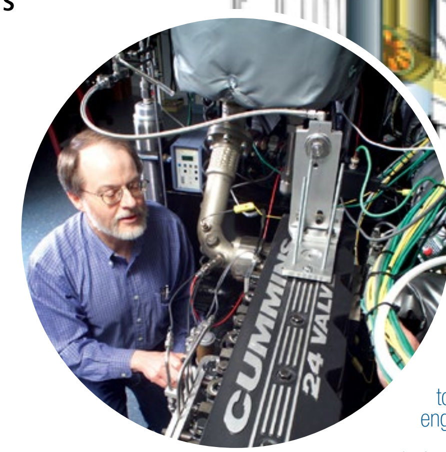
Sandia has a long history of working with industry to move our science and technology (S&T) into the marketplace. Our research into the science of combustion, for example, has had a significant impact on internal combustion engine fuel efficiency through longstanding partnerships with automotive manufacturers. In 1980, Sandia established the Combustion Research Facility (CRF), a DOE Office of Science (SC) collaborative research facility, to bring together our basic and applied research aimed at improving our nation's ability to use and control combustion processes. The CRF conducts research in tandem with university and industry. Visiting researchers have access to the CRF's state-of-the-art facilities and expert staff, and bring with them experience and knowledge that enhances and brings new approaches to CRF projects. A glowing example of our partnership efforts is a collaboration of CRF and modeling and simulation researchers with Cummins on their newest diesel engine—marketed in 2007 solely with computer modeling and analysis tools, which replaced the traditional build-and-test approach. Cummins achieved a 10%–15% reduction in development time and cost as they achieved a more robust design, improved mileage, and met all environmental and customer constraints.

The CRF's engine combustion research program led the development of the S&T foundation for diesel combustion. The research effort spanned more than 15 years and was largely funded by DOE. Sandia provided much of the detailed understanding of the physical and chemical processes that drive the very complex diesel combustion process. Other key contributors included Los Alamos National Laboratory (LANL, numerical framework for engine combustion models), Lawrence Livermore National Laboratory (LLNL, chemical kinetic models for combustion and emissions processes), and the universities of Wisconsin and Michigan (helped develop and validate many of the submodels for diesel combustion)—to name a few key collaborators. This understanding of diesel combustion was developed through the application of laser diagnostics in the CRF's optical engine facilities. The information was essential for developing the computational tools used by industry. CRF researchers are expanding the S&T foundation to include new, clean combustion strategies for high-efficiency engines utilizing future fuels, and developing the next generation of computational tools utilizing massively parallel machines.

Basic Science Research

These past successes and future accomplishments rely on our strong





Right: The "optical" cylinder, a new tool for diesel engine design.

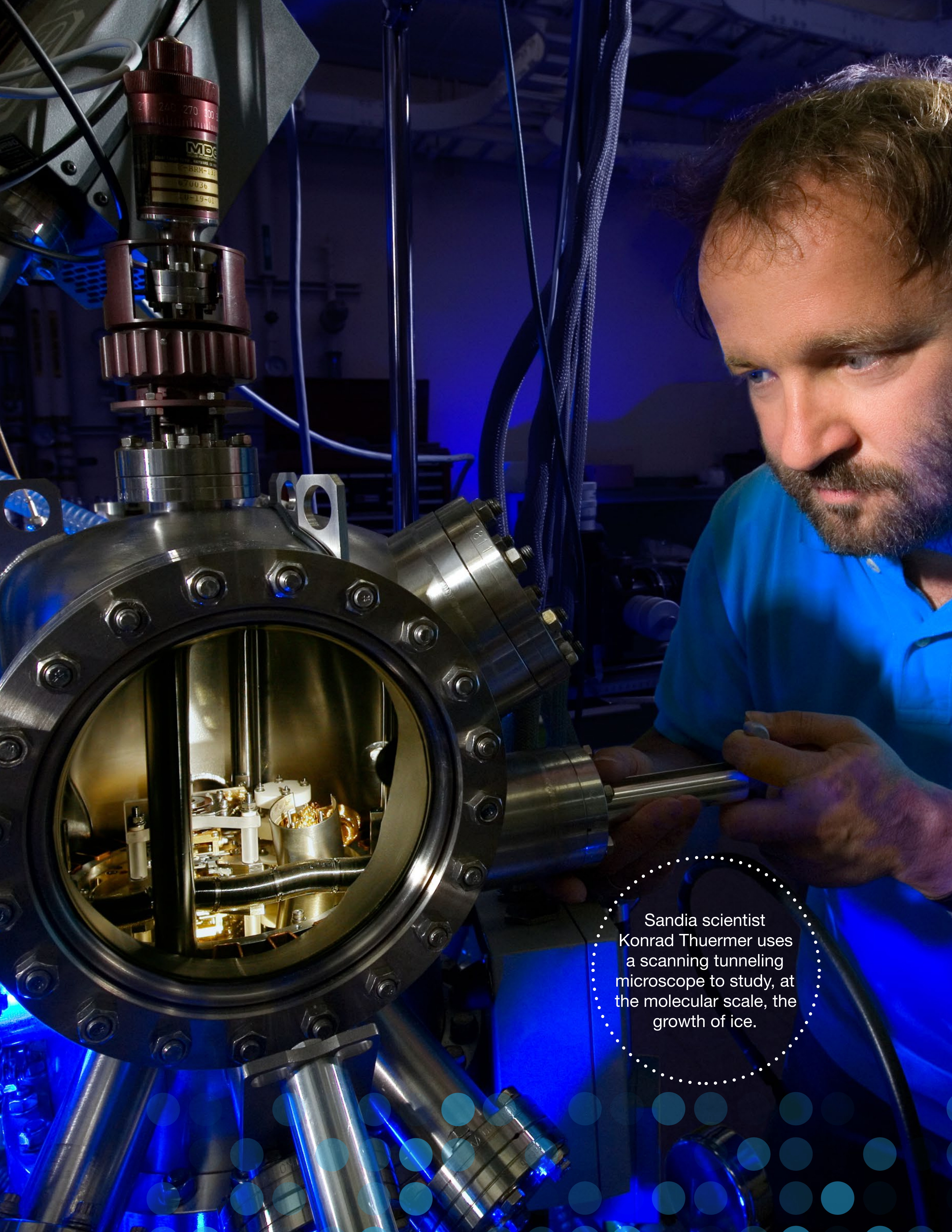
Left: Cummins Engine

foundational science programs. Sandia maintains its reputation in energy research through foundational research in important energy areas. Recently, Science Watch® published the results of its survey of scientific literature in the energy journals listed in the Science Citation Index. The 94 journals of the "Energy & Fuels" category published ~100,000 papers between 1998 and 2008. From that body of research, Science Watch identified Sandia National Laboratories as the most-cited institution in this research category, with 4,147 citations to its 395 papers.

In late 2009, Sandia announced its initial development of glitter-sized photovoltaic (PV) cells that could revolutionize solar energy collection. The millimeter-length crystalline silicon micro-PV cells will be cheaper and have greater efficiencies than current PV collectors. Microsystems-enabled PV (MEPV) cells require relatively little material to form well-controlled, highly efficient devices. MEPV cell fabrication uses common micro-electronic and micro-electromechanical systems (MEMS) techniques that leverage Sandia's NW competency at the Microsystems Engineering Science and Applications (MESA) facility. From 14–20 µm thick, MEPV cells are 10 times thinner than conventional cells, yet perform at about the same efficiency. MEPV benefits include improved performance, reduced costs, higher efficiencies, and new applications.

In the 21st century, Sandia has expanded its energy programs and partnerships to include climate research (because power generation and energy use are primary contributors to climate instability) and energy infrastructure security (because, as renewable energy power is integrated into the grid, the national power grid must initiate some fundamental improvements). These programs, in addition to our energy research, continue Sandia's tradition of exceptional service in the national interest. As it has since its founding, Sandia is working to provide the foundational science and engineering that underlies the nation's security. The Energy, Climate, and Infrastructure strategic management unit is working toward this goal with regard to our energy future.

Sandia's MESA (Microsystems Engineering Science and Applications) facility hosts state-of-the-art microfabrication capabilities and experts who work on many national security projects, including the ECIS MEPV research.



Sandia scientist Konrad Thuermer uses a scanning tunneling microscope to study, at the molecular scale, the growth of ice.

Strategic Framework

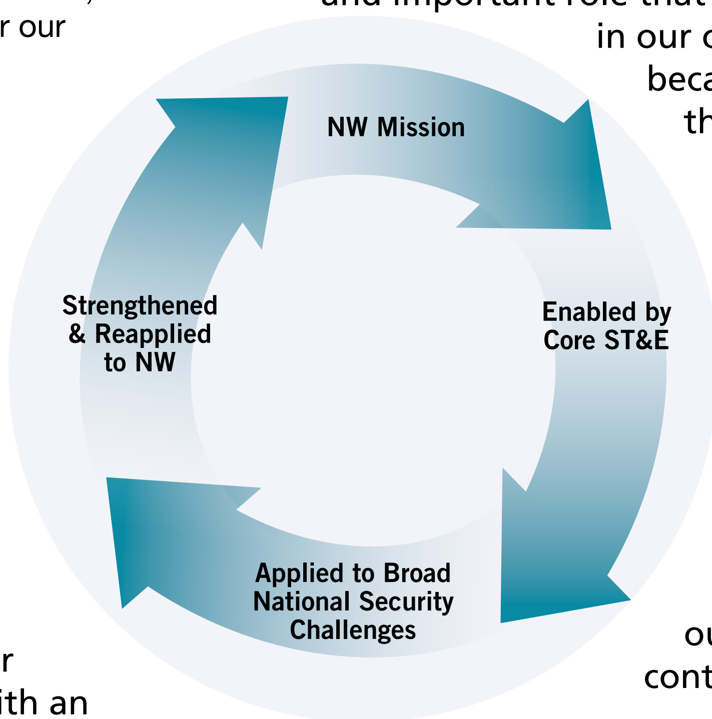
The Energy, Climate, and Infrastructure Security (ECIS) Strategic Management Unit (SMU) Strategic Plan documents the long-range planning process to define its vision, objectives, goals, and portfolio of research to support Sandia's national security mission.

Our strategy is based on our role as a national security laboratory to address the nation's most daunting science and technology challenges within the national security context. Our plan is informed and guided by the five Sandia Laboratory objectives:

- Deliver with excellence on our commitments to the unique nuclear weapons mission
- Amplify our national security impact
- Lead the complex as a model 21st century government-owned contractor-operated laboratory
- Excel in the practice of engineering
- Commit to a learning, inclusive, and engaging environment for our people

Within this context, the objectives and goals developed by this SMU seek to both leverage and enhance key competencies associated with our NW mission in order to amplify our contributions to broader national security in energy, climate, and infrastructure. The work of ECIS aims to further our engineering excellence with an emphasis on connecting deep science to engineering solutions. Finally, all of our work will be conducted in a manner that puts people first, assures the safety and health of employees and the public, protects the environment, and guards classified and other sensitive information.

The vision and set of enduring ECIS objectives described in this plan are congruent with foundational Sandia competencies built over decades. These competencies grew out of our historic mission in NW and a synergistic environment in which capabilities and expertise from our complementary missions support and strengthen one another. Ultimately, our mission is to enhance the security of the nation. In this SMU, due to the nature of the mission, the private sector has a unique and important role that is reflected in our objectives, because it is there that most energy and infrastructure technologies and solutions are deployed. Our overarching objectives are driven by both our historical contributions as



well as our fundamental role for the government as a national laboratory.

These objectives are as follows:

- Anticipate and enable government policy and regulatory decisions
- Steward competencies to support inherently government functions and services
- Accelerate private-sector deployment of solutions to meet U.S. policy objectives
- Support U.S. international engagement to solve national security challenges

As we developed our strategy and plan from these objectives, we faced the unique challenge that the nation does not currently have a well-articulated energy policy nor does the DOE have an enduring set of priorities and roadmaps that provide high-level integrated guidance. The DOE is now engaged in a Quadrennial Technology Review process, to which Sandia has contributed, to develop a framework that, in the future, we will be able to use for such guidance. While this is not yet available nor are clear governmental policies and priorities complete, there is general consensus at the national, regional, and state level on the most significant problems and challenges to our national security in this area. In our planning process, we reviewed these challenges and selected a set of five national-level problems across the energy, climate, and infrastructure sectors that reflect our priorities and guiding framework. These are

- Reduce our dependence on foreign oil
- Increase deployment of low-carbon stationary power generation
- Understand risks and enable mitigation of climate-change impacts
- Increase security and resiliency of critical infrastructures
- Strengthen the nation's science and technology (S&T) base in energy, climate, and infrastructure

From these challenges, we then created a set of five-year, outcome-focused goals that are consistent with our national laboratory role, our unique competencies, and our objectives. Each of these is described more fully in the following sections.

National Security Missions

Our Vision

To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

Access to reliable, affordable, and sustainable sources of energy is essential for all modern economies. The global demand for electricity will increase from 19.1 petawatt-hours (PWh) in the year 2008 to 32.5 PWh by the year 2035.[3]

This is driven to a great extent by the growing population in developing countries (note that 1.5 billion people, 22% of world population, presently do not have access to electricity). Meeting this need will have a profound impact on energy production/consumption patterns, on the environment, on the global economy, and ultimately on the global political atmosphere.
The future security of our nation will rely on our ability to address the energy, climate, and infrastructure challenges facing the U.S. and the world. The U.S. share of world consumption is presently around 20%. How we use this energy is shown in the upper figure on the opposite page. A parallel flow chart for our carbon dioxide (CO_2) emissions is shown in the lower figure on that page. Electricity generation and transportation are the two largest energy use sectors and, not surprisingly, they also are the largest contributors to U.S. CO_2 emissions. Together, they comprise around 74% of our consumption and CO_2 emissions. Innovative approaches in these two sectors would have tremendous impact to our national security.

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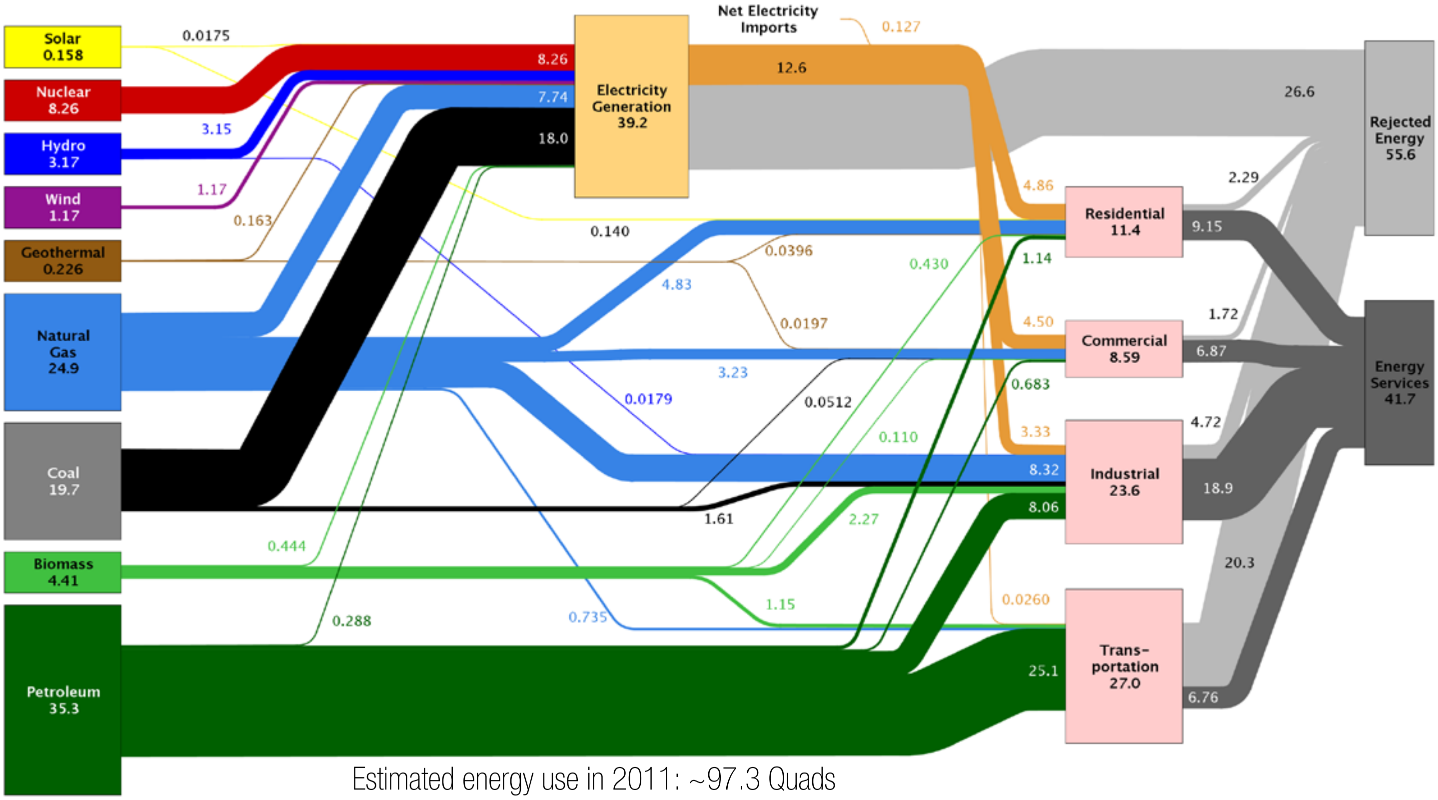
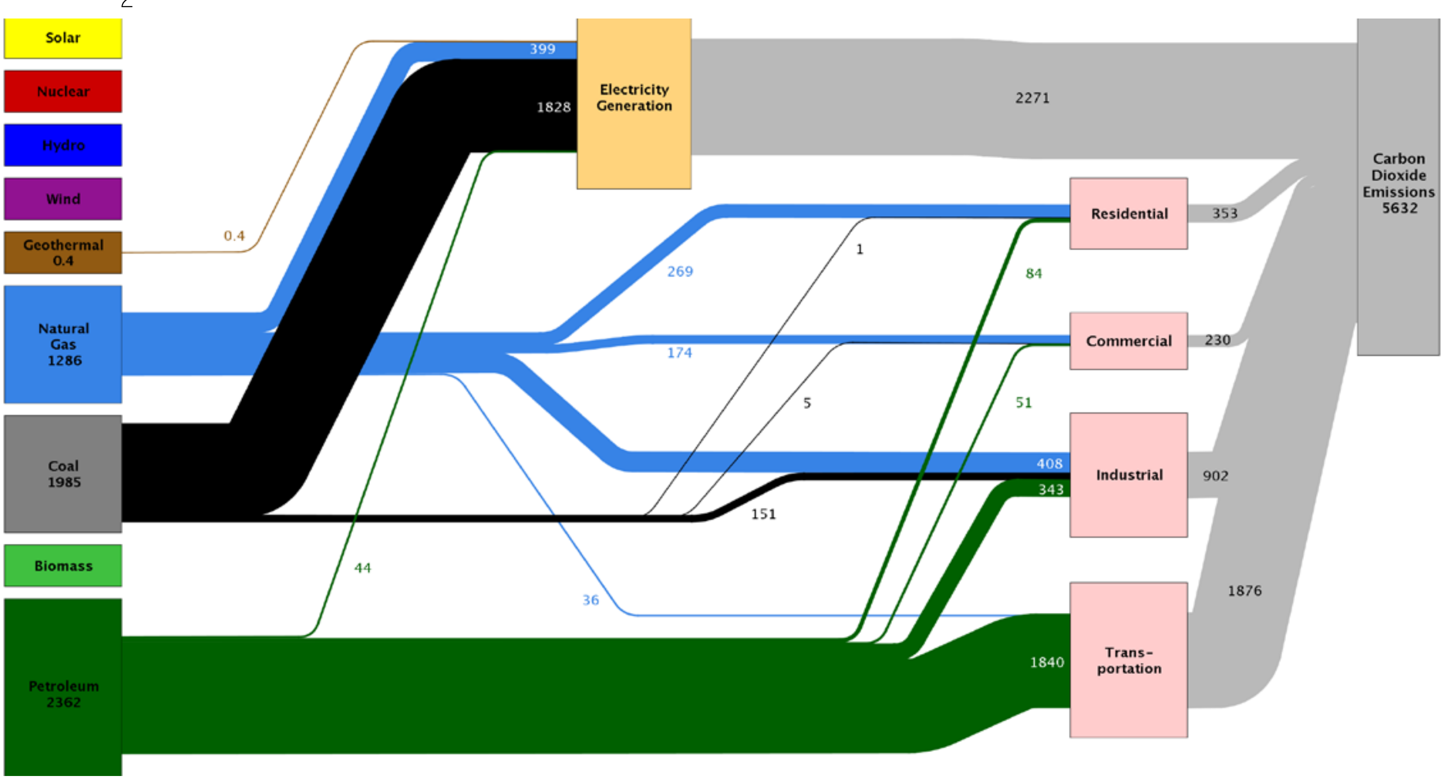
U.S. Energy Flows by Sector



Estimated energy use in 2011: ~97.3 Quads

[https://flowcharts.llnl.gov/content/energy/energy_archive/energy_flow_2011/LLNLUSEnergy2011.png and https://flowcharts.llnl.gov/content/carbon/carbon_emissions_2010/LLNL_US_Carbon_2010.png].

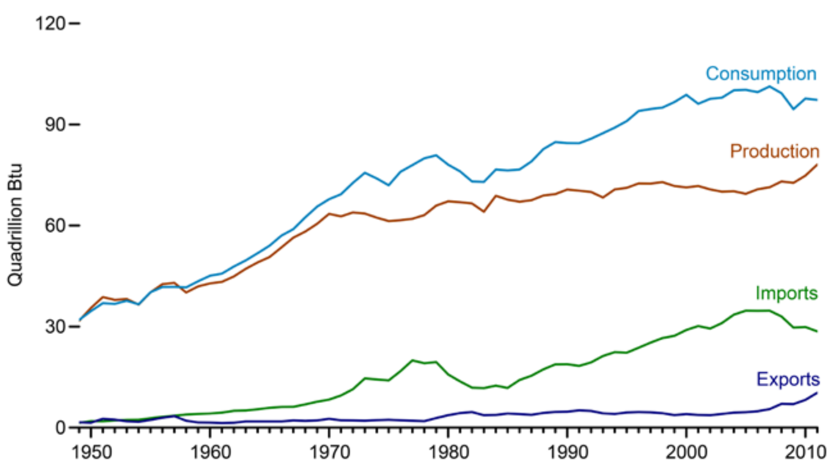
CO_2 Flows by Sector



Estimated U.S. Carbon Dioxide Emissions in 2010: ~5632 Million Metric Tons

Energy Overview

U.S. Primary Energy Overview 1949–2011



The U.S. was energy self sufficient through the late 1950s. The divergence between red and blue lines, indicates the extent to which we have become dependent on foreign oil (and to a lesser extent, since the late 80s, natural gas).

Source: U.S. Energy Information Administration, "Annual Energy Review 2011," September 2012, p. 4 [http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf].

sectors and, not surprisingly, they also are the largest contributors to U.S. CO_2 emissions. Together, they comprise around 70% of our consumption and CO_2 emissions. Innovative approaches in these two sectors would have tremendous impact to our national security.

It is interesting to note that the U.S. was energy self-sufficient until the late 1950s, when energy consumption began to outpace domestic production. In 2012, 57.3% of the oil consumed was imported, and 36.4% of that comes from unstable states. **Reducing our dependence on foreign oil** is of primary importance to our national security.

In working toward that goal, developing clean energy sources is a key strategy. This economic sector is undergoing tremendous growth with investments increasing at a 50% annual rate since 2004 and topped \$100B in 2007.[4] Policy is playing a central role in this development. Renewable portfolio standards, requiring electricity providers to obtain a minimum percentage of their power from renewable energy resources by a certain date, have been adopted by over 30 states and many countries. For electrical utilities to meet these standards on a large scale, **increased deployment of low-carbon stationary power generation** is needed.

Reliably delivering energy to its end-use points is vital to our national security and economic prosperity. We must **increase the security and resilience of our critical infrastructure**—make it resilient enough to compensate for interruptions and flexible/intelligent enough to incorporate the planned renewable energy sources (with their inherent variability in power generation). The national power grid is based on technology developed in the 19th and early 20th centuries, and much of it was built in the years surrounding World War II. This aging grid is susceptible to damage and outages from storms, accidents, and human error. The fragility of this system was unfortunately demonstrated in 2003 by the blackout that struck the Northeast. While this was an unusually widespread event, the Galvin Electricity Initiative tells us that each day roughly 500,000 Americans spend at least 2 hours without electricity in their homes and offices. Such outages cost our economy $150B each year.[5]

Economic prosperity is not all that is at stake. A failure in the power grid affects other critical infrastructure such as hospitals, fire and rescue, and military and police agencies. Interruptions put these security and safety institutions in jeopardy—an intentional disruption could have even greater consequences. To forestall such a situation, we must secure information access to our energy infrastructure.

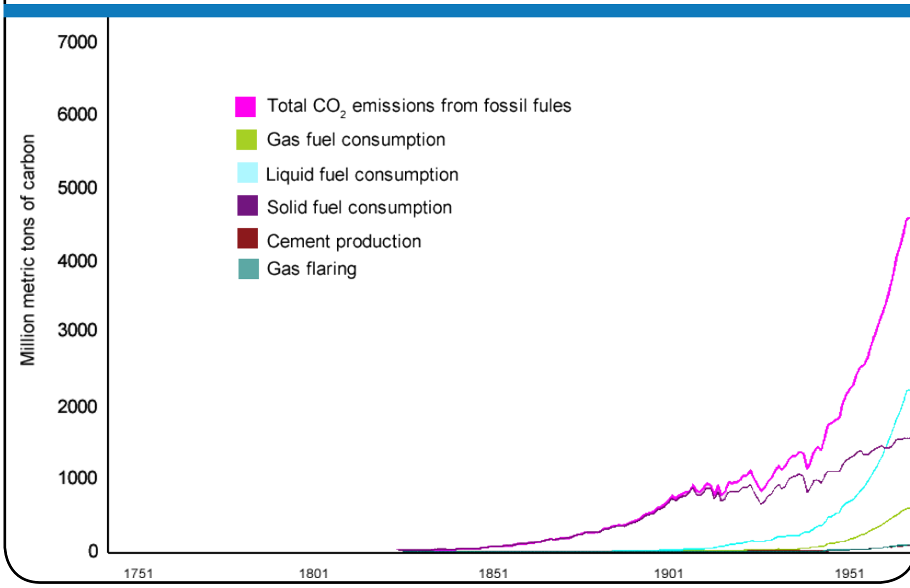
For the U.S. military, reliable, secure power is also essential. To function as they are intended, our military installations, tactical operations, and training all require secure and uninterrupted access to energy. According to the Defense Science Board Task Force on Department of Defense (DoD) Energy Strategy, the DoD is the largest single consumer of energy in the U.S. In 2006, the DoD spent over $3.5B for energy to power fixed installations. An essential element of our national security is assuring energy security for critical installations.

Intimately coupled to the increasing need for energy are the threats posed to our environment by emissions of greenhouse gases (GHGs) leading to climate instability. This hazard is fundamentally different from previously identified acid-rain-producing pollutants. Once we curtailed those other emissions, natural atmospheric processes neutralized these pollutants relatively quickly, and the environment began to recover. Carbon dioxide's effects are more subtle and slower acting. The residence time for CO_2 is ~100 years. The chart shown on the next page indicates the levels of these emissions since the beginning of industrialization and their rapid increase since the 1950s. Sandia's extensive competencies in systems analysis and uncertainty quantification couples with our foundational research capabilities to allow us to provide policy makers with usable (properly formulated and properly communicated) information that assists them in **understanding risks and enabling adapaptation to and mitigation of climate-change impacts**.

Aggressive national goals for reducing GHG emissions by 17% by 2020 and by 83% by 2050[6] will require major improvements in all aspects of our energy use. Achieving an 80% reduction of CO_2 by 2050 may seem a long way off. However, the U.S. automobile fleet turns over approximately every 20 years—therefore every car sold in the U.S. after 2030 must meet the 80% CO_2 reduction. Foundational research will be needed to develop new mitigation approaches and technologies to address the global GHG inventory—thus advancing credible carbon management strategies.

For the foreseeable future, fossil fuels will be an essential energy source for modern societies.

Global carbon emissions from human activities (1750–2004)



Source: Marland, G., T.A. Boden, and R.J. Andres, "Global, Regional, and National CO_2 Emissions," in Trends: A Compendium of Data on Global Change, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

New technologies will be a significant factor in credibly and economically managing fossil fuel energy production's effects on the environment and the climate we experience. Climate instability could also create geopolitical disruptions, changing the global balance of power.

A sound understanding of the potential socio-economic changes driven by climate is an essential foundation to enable a global climate treaty. We must develop a deeper understanding of climatic processes, which will provide the scientific foundation that will make such a treaty both possible and meaningful should the U.S. desire to enter into one. And, should climate instability effects become more pronounced, access to safe, secure, and sustainable sources of fresh water will become more difficult, and may shift. Under these circumstances, we must work to assure water safety, security, and sustainability.

To overcome these looming issues in energy generation, infrastructure security, and climatic effects, the nation requires science-based technological advances—not only in applied areas to refine and improve existing technologies, but in foundational science that will underlie the next generation of transformative technologies that will address the roots of these energy/infrastructure/climate challenges. It is clear that how we address and eventually meet these needs will have a broad impact on our standard of living and the national economy. Effective solutions will require scientific breakthroughs and truly revolutionary developments. We must facilitate these developments by **strengthening the nation's S&T base to accelerate innovation for energy, climate, and infrastructure security**.

Our future security is not assured without a strong national economy. The energy enterprise constitutes 8.3% of the U.S. gross domestic product[7] and approximately 9% globally. The growing green economy provides a tremendous opportunity for economic growth and leadership. This is now recognized internationally and the competition is fierce—particularly from China. Meeting targets on GHG emissions and improving energy security will require hundreds of billions of dollars of investment in renewable energy generation technologies, and this opens up the attractive prospect of an explosive growth in jobs in these new industries at a time when more traditional jobs are disappearing. The unanswered question for the developed world is where those jobs will be.

While countries such as the U.S., the UK, Germany, and Japan have all worked hard to be centers of green technological development, parts of the rapidly industrializing world have also seen the opportunity. Western governments are acutely aware of the need to build up their green industries quickly, or face being outdone by the rapid growth in China and India.

The ECIS SMU here at Sandia stands ready to play its part in supporting the nation in implementing the President's ambitious agenda to invest in clean energy, reduce our dependence on foreign oil, address the global climate crisis, and create millions of new jobs. A secure energy future will rely on industry. Central to our strategy will be to expand and deepen our partnerships with U.S. industry to accelerate the development of new energy and climate technologies.

In the ECIS SMU, our vision is building upon our 40 years of energy research programs and strengthening the coupling to our foundational systems engineering in the support of stockpile stewardship to **enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems**.

Sandia researchers hold up samples of their recently developed glitter-sized PV cells.

Our **Vision**

To enhance the nation's security and prosperity through sustainable, transformative approaches to our most challenging energy, climate, and infrastructure problems.

Guiding **Principles**

Our strategy has been guided by two central concepts:

- Industry plays the leading role in providing and adopting new energy and climate technologies.
- Policy and regulatory decisions at all levels of government drive the implementation of any new approaches to our nation's energy, climate, and infrastructure security.

ECIS National Security Missions

- Reduce our dependence on foreign oil
- Increase use of low-carbon stationary power generation
- Understand risks and enable mitigation of climate-change impacts
- Increase security and resiliency of the critical infrastructure hunes
- Strengthen the nation's S&T base in energy, climate, and infrastructure

10 Year **Objectives**

Objective 1

Anticipate & Enable Policy & Regulatory Decisions

Anticipate and enable sound government policy and regulatory decisions by providing timely and objective technology assessments and systems analyses.

Objective 2

Accelerate Solutions

Accelerate U.S. industries' innovation, development, and successful deployment of solutions to the nation's most challenging energy, climate, and infrastructure problems to meet U.S. policy objectives.

Objective 3

Steward Competencies

Create and steward enduring science, systems, and security competencies to support inherently government functions and services and anticipate national security challenges.

Objective 4

Support International Engagement

Support U.S. leadership in global energy, climate, and infrastructure challenges through strategic international engagement.

Energy, Climate, & Infrastructure Security

Program Areas & Goals

ECIS has four principal program areas each led by a director: Energy Security, Climate Security, Infrastructure Security, and Enabling Capabilities. Each program area has a set of five-year goals, aligned with the SMU objectives and national challenges that drive our internal investments. Program development resources are directly tied and

Energy Security

To accelerate the development of transformative energy solutions that will enhance the nation's security and economic prosperity.

The Energy Program Area consists of research programs in renewable energy systems; nuclear energy systems; energy for transportation; and energy efficiency.

Climate Security

To understand and prepare the nation for the national security implications of climate change.

The Climate Program Area is home to research programs for sensing and monitoring; modeling and analysis; carbon capture, sequestration, and management; and water systems.

tracked to these goals. Our program area goals are not intended to be fully comprehensive for the entire set of SMU activities but instead for the principal roadmap for priority investments. They align with federal program priorities, our current activities and competencies, and our focus for future impact.

Infrastructure Security

To secure the nation's critical infrastructure against natural or malicious disruption.

Enabling Capabilities

Provides a differentiating science understanding that supports the SMU and Sandia's mission technologies now and into the future.

The Infrastructure Program Area hosts Sandia's expertise and capabilities in cybersecurity; electricity transmission, distribution, and energy infrastructure; modeling and analysis; and energy assurance.

The Enabling Capabilities Program Area is home to the discovery science and engineering (basic research); systems analysis; regulatory and policy support activities; and Advanced Research Projects Agency-Energy (ARPA-E) efforts that support the other program areas in their efforts.

Energy Security

The Energy Security program area works to accelerate the development of transformative energy solutions that will enhance the nation's security and economic prosperity.

Energy security research at Sandia seeks to address key challenges facing our nation and the world. We work with the energy industry to improve current solutions and develop the next generation of technologies to convert, store, or use energy.

The ECIS SMU spearheads research into energy alternatives that will help the nation reduce its dependence on fossil fuels, combat the effects of climate change, and strengthen our energy security by providing new alternative fuel sources. Sandia's long history with geothermal, solar, and wind energy research has seen a vast increase in effort and intensity over the past 15 years and has also been supplemented in recent years with efforts in biologically based fuels: biomass from nonfood plant sources and algae—both of which can be grown on land unsuitable for farming. Sandia researchers are also pushing back the boundaries of the energy frontier with revolutionary projects like Sunshine to Petrol, which converts CO_2 and water into synthetic fuels.

Sandia's Energy for Transportation activity studies reacting flow fluid dynamics, combustion chemistry, engine combustion, thermal/fluid mechanics and heat and mass transfer, and hydrogen & combustion technologies to develop a science-based, first-principles understanding of combustion's properties and behavior in order to help industry

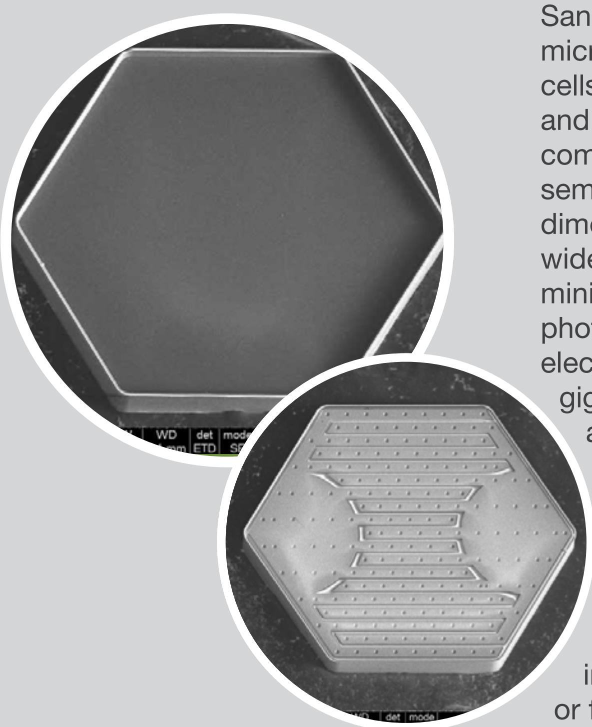
- improve current engine technologies to be more efficient,
- reduce or eliminate a variety of harmful engine emissions, and
- develop the next generation of engines that can efficiently use new fuel formulations and low-carbon alternative fuels that will help us reduce our impact on the environment.

Our researchers also work to improve the processes in the nuclear power enterprise by perfecting new concepts like the small modular reactor (SMR) that will contribute to the next generation of nuclear power generation and by developing options for disposal of waste from this important electric power source.

Energy Security Goals

1 Develop advanced technologies and systems that will enable renewable energy penetration to grow from 13% (in 2011) to 20% by 2020 in the U.S. power grid and at military installations.

Microsystems-Enabled Photovoltaics (MEPV)



Scanning electron microscope (SEM) image of the front (left) and back (right) sides of a 250-um-wide c-Si PV cell fabricated from a (111) oriented wafer.

Sandia has developed microscale photovoltaic (PV) cells using microsystems tools and manufacturing techniques commonly used in the semiconductor industry. With dimensions as small as 100 μm wide and 1 μm thick, these miniaturized PV cells convert photons from any light source into electricity with the scalability for gigawatt electricity generation and the versatility to be incorporated directly into handheld devices.

These cells do not have electrical contacts on the front side and can be installed in flexible, moldable, or flat-plate formats in sizes that conform to the shapes and contours of natural terrain, large structures, vehicles, and mobile electronics—blending into a device's look, feel, and functionality. The stacked cell designs are particularly well suited for power applications that require high-watt production per unit area or weight (e.g., manned or unmanned aircraft, satellites, and CPV).

Through the methodical mass-production process, commercial microscale PV cell conversion efficiency can be improved to the full potential of the semiconductor material and evolving system designs, and overall PV system material costs can become of lesser significance than manufacturing costs. When that happens, PV technology can migrate from its currently shallow cost-reduction trajectory to one that is noticeably steeper. It can ultimately make microscale PV cells the lowest-cost electricity option for application markets such as mobile power, wholesale electricity from solar utility farms, and retail electricity from flat commercial rooftops.

Both the DOE and the DoD have set aggressive goals to increase the penetration of renewable energy resources in U.S. civilian and military infrastructures, respectively. A spectrum of renewable-energy technology options will be needed to meet diverse load demands, climate constraints, and mission requirements. Sandia supports this goal through innovative research and development (R&D), testing and evaluation, and system demonstration and deployment of novel wind, water power, PV, CSP, and geothermal energy technologies. Sandia executes on this goal while addressing the energy surety attributes of safety, security, reliability, sustainability, and cost effectiveness to provide the most robust renewable-energy technology options.

2 Create nonpetroleum-based liquid transportation fuel options such as solar fuels and biofuels.

The nation has a variety of options for "energizing" or fueling the transportation section, but alternatives to petroleum pose challenges in terms of cost, infrastructure compatibility, scale, and in some cases, technical feasibility. To address the nation's vulnerabilities with regard to energy security in the transportation sector, Sandia's is advancing two "alternative fuel" options: solar fuels and biofuels. In particular, Sandia aims to demonstrate technologies capable of producing fuel from sunlight at 10% lifecycle efficiency or greater and strives to develop advanced

Sunshine to Petrol (S2P)

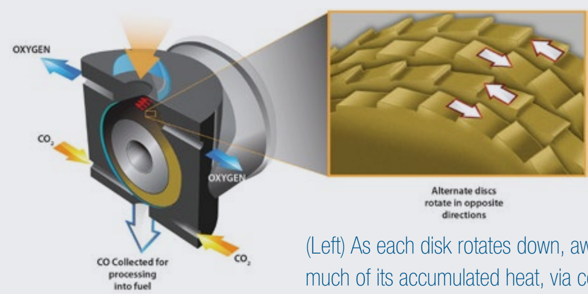
The Sunshine to Petrol (S2P) team is building capabilities and expertise to utilize concentrated solar thermal energy to split CO_2 and H_2O into synthesis gas (CO and H_2), a precursor to synthetic drop-in liquid transportation fuels. In this manner, such fuels can be produced sustainably, renewably, and domestically, with low-net-carbon emissions.

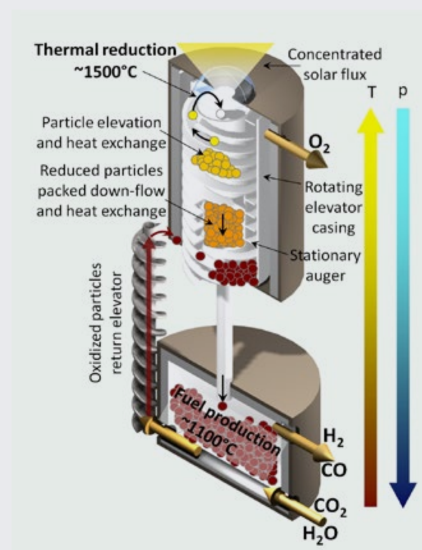
To accomplish this, the team has developed and built a novel continuous flow, recuperating thermo-chemical heat engine, called the CR5, driven by direct reactive-material heating by concentrated solar irradiation. The CR5 represents the current state of the art, and recently demonstrated a solar-to-CO production efficiency of 1.7%.

Within the next 5 years, the S2P team plans to demonstrate a solar-to-chemical energy conversion at continuous 12% device efficiency.

To realize this concept, the team must address complex chemical, materials science, and engineering problems associated with the techno-economics of a full system (sunlight to liquid hydrocarbon fuels) prototype engine and the crucial enabling metal-oxide working materials. A 2nd-generation reactor has been designed and is under construction; this new design incorporates lessons learned from the previous reactor and is anticipated to operate at higher efficiencies.

Although S2P is years away from a market-ready device, with adequate and sustained resources, the team anticipates a program of continuously improved generations of materials, reactors, and S2P systems, a new generation every three years with significant improvements in performance (sunlight-to-fuel efficiency), greater durability, and reduced cost, with a goal of market deployment by 2021.





(Left) As each disk rotates down, away from the CR5 reactor's sunlight aperture, it transfers much of its accumulated heat, via convection, to the disks on either side. This recuperation and exchange of heat between disks is the key to the CR5 device's effectiveness. (Right) Gen-2 solar thermochemical reactor, which decouples reduction and oxidation steps while maintaining heat recuperation and resulting in higher efficiencies. (SD11975)

conversion technologies for fungible biofuels derived from lignocellulosic biomass and algae.

Given today's transportation energy infrastructure and the effectiveness of our current suite of liquid fuels, replacement solutions will both be difficult and take time to develop. Sandia has leveraged existing capabilities and resources to begin to answer some of the fundamental questions and approaches to this dilemma. Initial results have shown great promise and support the viability of efficiently and affordably producing clean fuels from the sun and domestic biofuel resources. Industry investments and partnerships will be critical to fully realize the opportunity solar fuels present.

Our multi-institutional Sunshine to Petrol team is working to develop/demonstrate 12.5% sunlight-to-syngas energy conversion and analysis for a system design to achieve >6% end-to-end sunlight to fuel and a roadmap to >10% lifecycle sunlight-to-fuel. The team has built a prototype thermochemical engine which has been tested at Sandia's NSTTF. Sandia participation in the Joint Bioenergy Institute (JBEI) is focused on developing and demonstrating fungible

National Energy Goals[6]

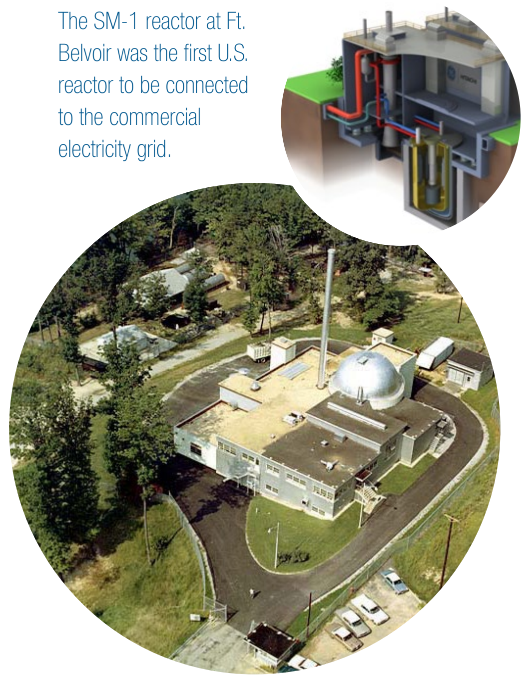
- Reduce energy-related GHG emissions by 17% by 2020 and 83% by 2050, from a 2005 baseline.
- By 2035, 80% of America's electricity will come from clean energy sources.
- Support deployment of one million plug-in electric vehicles on the road by 2015.

biofuels from biomass and algae. Sandia leads the lignocellulosic deconstruction efforts of this exciting multi-institutional endeavor.

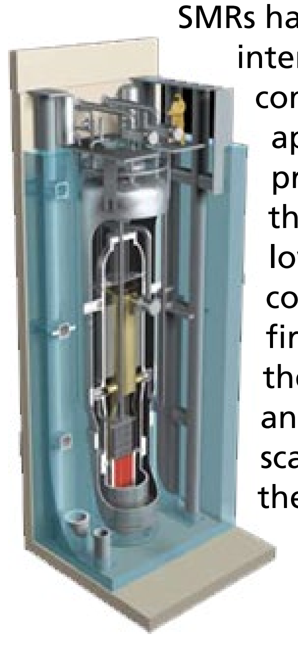
3 Develop reactor design and support systems to demonstrate the application of small, modular reactors to fulfill DoD mission goals for energy security.

To address energy security while simultaneously enhancing mission assurance at domestic facilities, the DoD will accelerate innovative energy and conservation technologies from laboratories to military end users. The surety microgrid concept is to place power-generating facilities and energy storage within the military installation.

The SM-1 reactor at Ft. Belvoir was the first U.S. reactor to be connected to the commercial electricity grid.



SMRs have considerable DoD appeal—primarily for their matched power output and the possibility of location within DoD bases for grid independence and security. SMRs have DOE interest for their commercial appeal primarily for their expected lower capital costs to first power, their size and modular scalability, and their benefits of carbon-free energy production. Sandia capabilities present an opportunity to provide the systems analysis necessary for the demonstration of nuclear power as an effective solution at the right price for mutual DOE and DoD energy security goals. Sandia's assessments of military energy security, activities in DoD logistic support, SMR design and construction, and reactor safety assessment position us to facilitate the DOE demonstration of an SMR at a DoD base.



The small, modular reactor concept places a sealed reactor underground wherever electricity is needed.

4 Complete a deep borehole disposal system demonstration project with industry that will transform nuclear waste management.

The U.S. nuclear industry has produced about 62,500 metric tons of spent nuclear fuel. Congress assigned responsibility to the DOE to site, construct, operate, and close a repository for the disposal of spent nuclear fuel and high-level radioactive waste.

With the closing of the Yucca Mountain site, the nation is exploring the options for the safe disposal of this high-level radioactive waste. Due to an emphasis on mined repositories and concern regarding retrievability, deep borehole disposal (DBHD) is a concept that has been discussed for many years, but never pursued despite several advantages. A full-scale demonstration of a DBHD system will

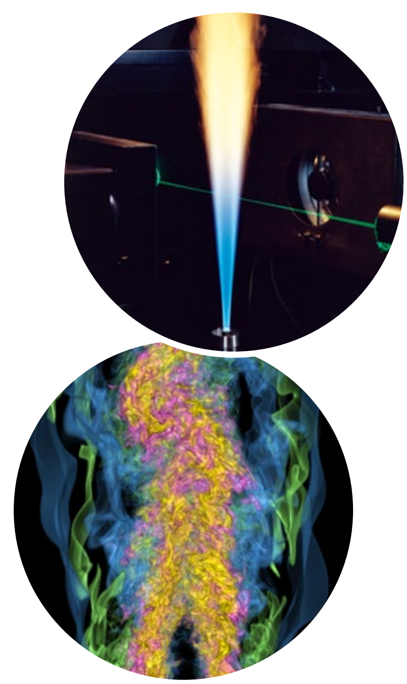
- secure U.S. leadership in repository sciences;
- close the fuel cycle with permanent, secure waste disposal;
- address political/regional equity concerns over hosting a single repository;
- provide factual data to support analysis of cost savings; and
- create a permanent disposal method that is highly proliferation resistant.

5 Provide for the science-based design tools necessary for industry to reduce carbon dioxide and petroleum footprint of the transportation fleet by 25%.

Transportation by automobiles and trucks accounts for about 71% of our oil use[8], and one-third of our greenhouse gas (GHG) emissions. The American Clean Energy and Security Act of 2009 describes goals for clean energy, energy efficiency, reducing GHG emissions, and creating clean-energy jobs. A certain and significant part of any path toward reducing both oil use, and concurrently, GHGs is to develop more fuel-efficient power conversion systems for vehicles and accelerate the introduction of low-net-carbon fuels.

The potential impact of fuel-efficiency improvements on reducing oil use and GHG emissions is enormous. As a nation, we urgently need to provide faster innovation, development, and introduction of high-efficiency, clean power sources for vehicles. Such investments are needed to grow jobs and bolster U.S. leadership in transportation.

Because no single technology is the panacea for the future, it is incumbent to work on each advanced technology with the expectation that the market will determine the mix of engines powering our vehicles by mid-century. The Transportation Energy element of Energy Security is working on future ultra-efficient internal combustion engines using liquid fuels (either petroleum- or biomass-based), advanced battery materials and technologies including the testing of battery packs, and the technologies to support the successful introduction of fuel cell vehicles into the market.



CRF researchers employ novel laser diagnostics (top) and HPC modeling and simulation (bottom) to better understand the physics of combustion (e.g., chemical dynamics, combustion kinetics, flame chemistry, and reacting flows).

Solid State Lighting (SSL)

Lighting uses ~22% of U.S. electricity, ~$50B/year. SSL can reduce that energy use by 3–6 times. SSL devices use semiconductors (crystalline, organic, or polymer light-emitting diodes) for light rather than filaments/plasma/gas. Compared to incandescent lights, SSL devices create visible light with greatly reduced heat generation/parasitic energy loss, less mass provides better shock/vibration resistance than brittle glass tubes and long filaments, and they have much greater wear lifetimes.

SSL devices are based on wide bandgap semiconductors, a materials system for which Sandia has long-standing experience and expertise.

SSL lamps are replacing incandescents in many applications requiring durability, compactness, cool operation and/or directionality—they're used in modern traffic signals; vehicle, street/parking-lot, and train marker lights; building exteriors; and remote controls.

However, SSL devices remain ~5–10 times away from their potential. Sandia's SSL team studies

- energy-efficiency-limiting mechanisms and defects in SSL materials;
- electricity conversion to light using radically new designs (luminescent nanowires, quantum dots, and hybrid architectures); and
- energy conversion processes in structures that are smaller than light wavelengths.

Sandia's Photovoltaics (PV) Regional Test Center (RTC)

The conceptual site plan for the RTC at Sandia's NSTTF. The 8-acre Site 0 has four 300 kVA transformers for 1.2 MW DC capacity. Site 0's road, electrical, and communications infrastructure are in place. Expansion into Site A is covered in the preliminary plans.

To assure stakeholders (customers, banks, insurance companies) that a new PV technology will work with high fidelity and robustness over time, the DOE funded five RTCs to perform long-term, real-world testing and monitoring. The RTCs, collaboratively led by Sandia, NREL, and other RTC members, are designed to host identical, highly instrumented 30–300 kW PV systems in hot-dry, hot-humid, steppe, and cold-humid climates.

The RTCs leverage Sandia expertise in PV testing, research, performance modeling, and reliability. The Sandia-based RTC supports 1 MW of PV systems plus baseline test equipment, labor, and data analysis. Together, the RTCs demonstrate methods to show whether PV systems are sufficiently understood to project performance/reliability in other system configurations and environments.

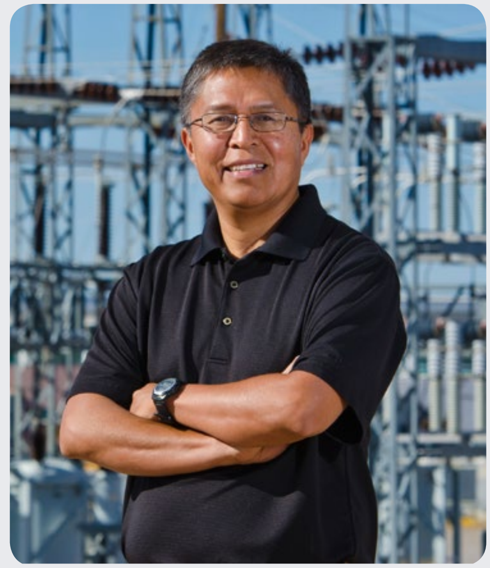
- The RTCs will establish data ownership and transparency guidelines to encourage manufacturer participation.
- RTC standards will define the range of data collected, procedures for collecting and filtering data, operations and maintenance (O&M) processes, and modeling parameters.
- The validation plan is based on the testing and monitoring needed to develop appropriate standards for performance validation, model validation, and field monitoring practices. Validation protocols will accommodate multiple sampling levels to confirm a product's conformance to specifications.
- The validation process compares actual performance/reliability against manufacturer predictions in different climates. The RTC team will determine the uncertainties and whether those uncertainties change in different climates.
- Data analysis will also be used to develop protocols for PV module, string, and block monitoring to optimally support O&M at working installations.

Stan Atcitty Honored by President Obama for Early Career Accomplishments

President Barack Obama named ECIS researcher Stan Atcitty as a recipient of the Presidential Early Career Award for Scientists and Engineers (PECASE). This is the highest honor bestowed by the U.S. government on outstanding scientists and engineers who are early in their independent research careers. Stan is among 96 researchers (including 13 from DOE laboratories) from 11 federal agencies named PECASE recipients in 2012.

Stan was nominated for the PECASE award by DOE's Office of Electricity Delivery and Energy Reliability (DOE-OE). He was recognized "for advances in power electronics for the electric grid including the development of an ultra-high-voltage silicon-carbide thyristor and a high-temperature silicon-carbide power module, for research on grid integration of energy storage, and for mentorship in the Native American community." These two power electronics projects as well as the emitter turn-off thyristor and the fiber-optic transducer were honored with prestigious R&D100 awards in 2011, 2009, and 2003, respectively.

Stan leads the power electronics subprogram as part of the DOE Energy Storage Program, which focuses on increasing power conversion system performance in grid-tied and off-grid energy storage systems. These systems will ultimately improve the security, quality, reliability, flexibility, and cost effectiveness of the existing electric utility systems. Stan's semiconductor work allows next-generation smart-grid power electronics systems to be built up to 10 times smaller than current technologies. Their performance advantages are expected to spur innovations in utility-scale power electronics hardware and to increase distributed energy resource accessibility and use.



President Obama named Dr. Stanley Atcitty among 13 U.S. Department of Energy-funded researchers as recipients of the award which is the highest honor bestowed by the U.S. government on outstanding scientists and engineers, who are early in their independent research careers.

The Consortium for Advanced Simulation of Light Water Reactors (CASL)

CASL was established by the U.S. Department of Energy as the nation's energy innovation hub for nuclear energy advanced modeling and simulation. This hub, led by Oak Ridge National Laboratory and funded in 2010 at $122M over five years, is developing a "virtual" nuclear reactor that will address three critical areas of performance for nuclear power plants:

1. reducing costs for nuclear-generated electricity by enabling power uprates and lifetime extensions for existing and future plants,
2. enabling higher fuel burn-up to reduce the volume of nuclear waste, and
3. enhancing nuclear safety.

Sandia is one of ten partner institutions in CASL (see accompanying illustration), whose scientists and engineers conduct research activities with a very high degree of technical interaction and collaboration using an advanced "telepresence" videoconferencing system and monthly physical "collocation weeks" at ORNL.

Sandia scientists are playing leading technical roles in developing the virtual environment for reactor applications (VERA), which will address the challenging operational and safety problems described above. Sandia is contributing key computational technologies, including advanced simulation codes; multiphysics coupling methods; solver libraries; and tools for verification and uncertainty quantification that comprise VERA's foundation. Additionally, Sandia is leading efforts to develop and integrate these capabilities with other codes in VERA, which was recently released by CASL for use by its nuclear industry partners through the Radiation Safety Information Computational Center.

The Consortium for Advanced Simulation of Light Water Reactors.

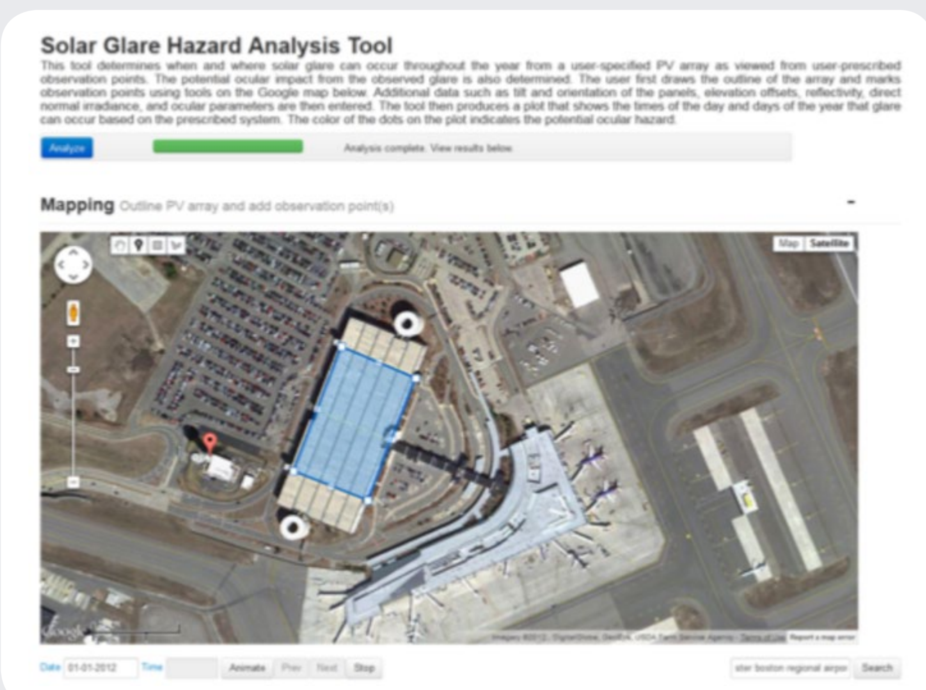
Solar Glare Hazard Analysis Tool (SGHAT)

With growing numbers of solar energy installations throughout the U.S., the potential impact of glare from photovoltaic (PV) arrays and concentrating solar collectors has become an increasing hazard for pilots, air-traffic control personnel, motorists, and others. The Federal Aviation Administration (FAA) announced that they will disallow new solar energy installations near airports unless a quantified analysis of potential ocular hazards from glint and glare is performed. The California Energy Commission (CEC), FAA, Air Force, and Solar Energy Industries Association have also requested tools/methods to evaluate glare to ensure safe solar power system permitting.

Glare viewed from the air traffic control tower at Manchester/ Boston Regional

Sandia developed a web-based interactive tool that evaluates and quantifies potential glint and glare impacts from solar energy installations. It provides a quantified assessment of (1) when and where glare can occur throughout the year for a prescribed installation, and (2) potential ocular impacts at locations where glare occurs. The calculations and methods are based on analyses, test data, and models developed to evaluate ocular hazards and validated by Sandia since 2009.

The tool presents the results in a simple easy-to-interpret plot that specifies when glare will occur, with color codes indicating the potential ocular hazard. SGHAT results have been confirmed with observations at Manchester/Boston Regional Airport and other sites. The tool can also predict relative energy production while evaluating alternative designs, layouts, and locations to identify configurations that maximize energy production while mitigating the impacts of glare; thus, it also serves as a design optimization tool.

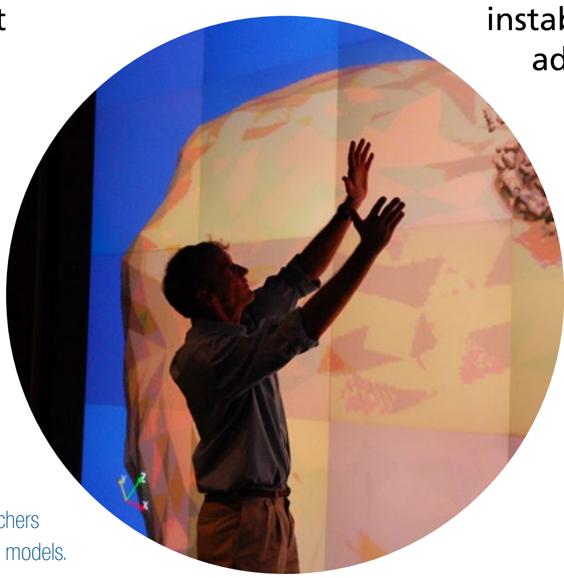


Screen image of SGHAT analysis of Manchester/Boston Regional Airport. PV array (blue outline) and observation points (red marker) are entered using tools integrated with Google Maps.

Climate Security

The Climate Security program works to understand and prepare the nation for the national security implications of climate change.

Our nation's fundamental security requires not only military capability and infrastructure, but also stability and predictability in a host of other areas ranging from energy supply, communications, and financial markets to the nation's preparedness for natural disasters and long-term changes in our environment, such as shifts in climate. It is well documented in the geologic record that the Earth's climate is not stagnant but changes continually and sometimes abruptly. Abundant scientific data point to Earth's present-day warming, and the nation must be prepared to deal with specific consequences of an evolving climate. Sandia's many technical capabilities, including geosciences, modeling and simulation, technology development, and data analysis provide a means to assess the effects of climate change on our national security. The impacts may range from international instability, to the need for additional electricity for heating and cooling, to more frequent extreme weather events. Sandia's Climate Security program works to understand and help address the impacts of climate change on the nation.

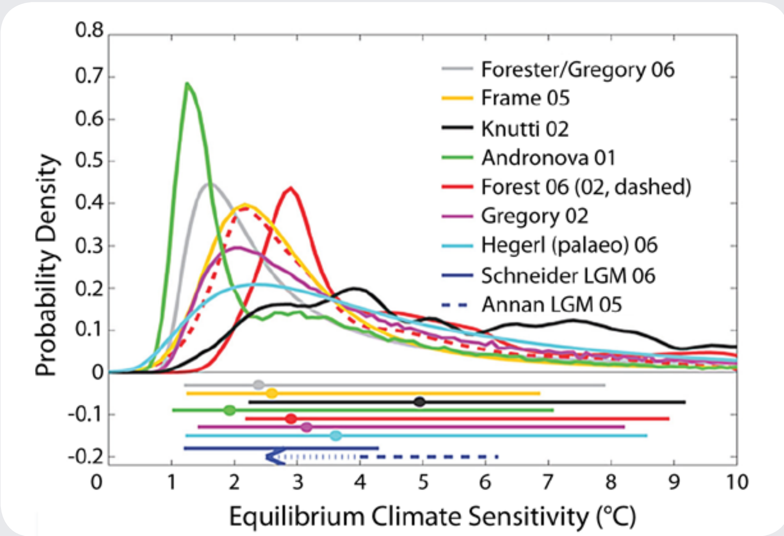


Sandia researchers review climate models.

Through a multipronged research approach, the Climate Security program seeks to

- improve our understanding of Earth's climate processes through more accurate, sensitive, and comprehensive sensing and monitoring;
- reduce GHG emissions by understanding their sources through coupled advanced measurement and analysis methods for climate treaty verification and policy support
- predict with greater accuracy and precision the possible outcomes of climate processes by applying that data to climate models with greater and greater resolution;
- quantitatively assess the uncertainties of socio-economic ramifications related to climate change;
- mitigate climate-change impacts by fostering

Sandia Studies the Effects of Climate Uncertainties on U.S. States

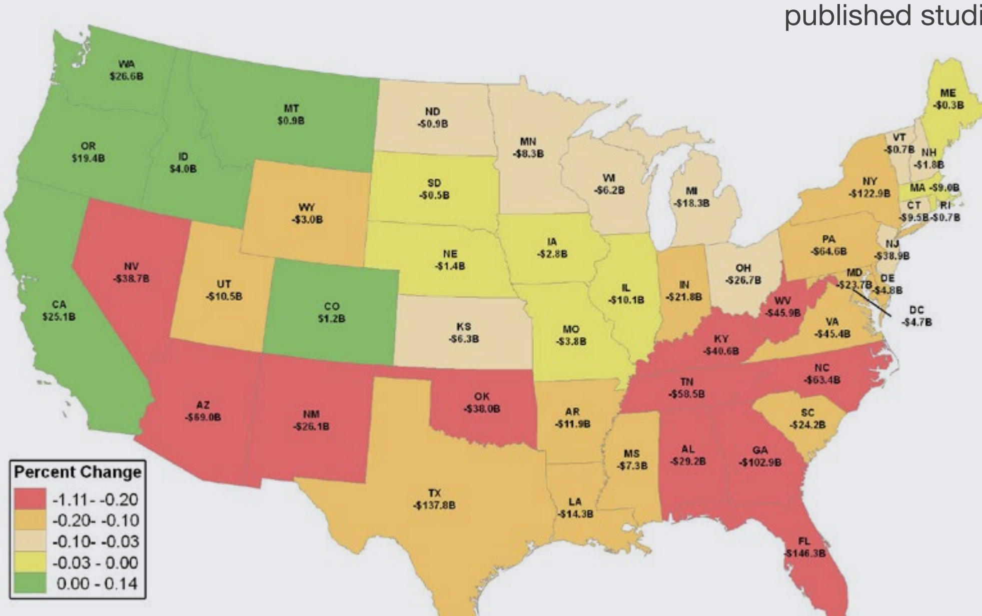


Source: Backus, G., "Assessing Near-Term Risk of Climate Uncertainty: Interdependencies among the U.S. States," Sandia Report SAND2010-2052, May 2010, p. 33.

Climate change's extent/future dynamics are highly uncertain. Global warming models in the UN's Intergovernmental Panel on Climate Change (IPCC) 2007 Assessment Report are skewed toward larger temperature changes (above). These skewed probability distributions illustrate future climatic condition uncertainty despite advances in climate science and the computational modeling of climate dynamics.

Understanding climate change risk will assist policy makers in choosing actions that could avoid the realization of those risks. Sandia researchers generated the an integrated economic assessment of climate risk among the contiguous 48 states. Using IPCC climate predictions, many Sandia scientists combined their expertise in uncertainty quantification, risk assessment, climate science, hydrology, infrastructure impacts, and macroeconomic analysis to develop a state-level risk assessment of climate change impacts through the year 2050. The most uncertain impact of the predicted climate change characteristic, precipitation, was used to assess economic impacts associated with water availability.

The potentially realized higher temperature and adverse precipitation conditions implied by the climate change probability distribution pose disparate consequences for the states across the U.S. While California and Colorado suffer the negative impacts from the loss of precipitation often noted in previous studies, worse conditions in surrounding states cause population in-migration that lead to a net benefit in California and Colorado economic conditions. In addition to the risk assessment and level of detail, this dynamic interaction among the states is a critical element that is missing from previously published studies.



Risk: the combination of potential consequences and the probability of those consequences occurring.

Potential state level impacts of climate change on gross state product from 2010–2050 in billions of 2008 dollars.

scientifically sound, reliable, and economically reasonable next-generation technologies and processes for fossil-fuel energy generation and emission sequestration; and
- address water-scarcity issues that have been/potentially will be brought about by climate- change processes, on both the domestic and international levels, to enhance security and stability.

Climate Security Goals

1 Assess U.S. security impact risks by modeling climate and human response at the regional level with quantified uncertainty.

This goal is important to the Sandia program and the international research community because we still cannot predict how climate will behave at a fundamental level. We must reduce uncertainty, but a more efficient approach is to first quantify the uncertainty that exists. Uncertainty quantification (UQ) methodology works to identify "important" areas of uncertainty—where an uncertainty will cause the widest variability in the computational model's outcomes. As UQ researchers identify these factors, they can guide the climate science community to where their research efforts can be best applied to reduce overall system uncertainty.

Most climate-research scientists/programs focus on predicting the change in the global mean temperature. Sandia's Climate Security program focuses on answering, "What is the risk that the change will be greater than the expected mean change?" Our research effort explores how can society adapt to a larger-than-expected change in global temperature and understanding the national security implications of those required adaptations. Our program is developing concept models in computational simulation framework and systems models of the interactions between physical and social economic factors—working to predict/understand societal behavior in reaction to climate change scenarios.

Other Climate Security modeling efforts focus on the physics of climate change. We have developed a sophisticated atmospheric model—the most highly resolved global atmospheric model available, with a resolution of 1/8 of a degree or ~12.5 km per grid element. We developed the core algorithms and are running it at Sandia. We will provide this content to international process of assessing climate. It will be basis of future Community Earth Systems Model (CESM, DOE/National Science Foundation climate model) and part of future IPCC projections.

2 Develop and deploy monitoring, simulation, and analysis capabilities that position Sandia as a national leader in polar research.

Climate research has shown that changes are amplified in Arctic regions (2–3 times), in part because water undergoes a seasonal phase change there with large changes in albedo and energy absorption. These climate disruptions, warmer atmosphere and seas, are becoming highly significant from a national security perspective.

- ***Resource extraction***. As the Arctic becomes more accessible, many nations (those bordering the Arctic Ocean and others that do not) are preparing to engage in vigorous competition for the region's natural resources, previously deemed too difficult or expensive to extract.
- ***Ocean access***. As sea ice becomes less prevalent in

Understanding Climate Change via Alaska's North Slope

Sandia researchers' work on the cold tundra of Alaska's North Slope is helping to transform our scientific understanding of what the future may hold for Earth's climate. The Arctic is predicted to undergo more intense changes than any other region. Yet, comparatively little is known about those specifics. Measurements from the Atmospheric Radiation Measurements (ARM) North Slope facilities provide hard data on clouds, aerosols, and visible and infrared radiation—improving the accuracy and reducing possible sources of error in climate models through a better understanding of cloud and aerosol life cycles, cloud-aerosol interactions, and radiative processes.

This information is so desirable that the DOE Office of Science has allocated additional funding during the next two years through its Biological Environmental Research (BER) arm to build new facilities and buy equipment for another ARM site. Also to be managed by Sandia, it will be deployed for up to five years at a location 166 miles away from Barrow, Oliktok Point. The program will install a ground station of six prefabricated buildings and stock it with Doppler and high-spectral-resolution lidars, radar, and radiometers, along with meteorological equipment and other sensors. An available Air Force hangar will shelter unmanned aerial vehicles and tethered balloons, possibly owned by a university in collaboration with the Office of Science. These will fly north from Oliktok Point for distances that may span several hundred miles, for additional atmospheric data collection.

The newly installed x-band scanning ARM precipitation radar operates from atop the Barrow Arctic Research Center.

the Arctic, the Arctic Ocean is more readily accessible for transportation by nonhardened vessels, significantly increasing the requirements for search, rescue, and emergency response.

- ***Security concerns***. A frontier that used to be secured largely by the difficulties of surmounting the challenges of a permanent ice pack is now being exposed to commercial activities—creating new operational requirements for the militaries of the nations who border the Arctic Ocean.
- ***Greenhouse gas emissions***. Increasing GHG and black carbon emissions are having more of an impact on the Arctic than on other areas of the world. Reducing these emissions will require concerted efforts to reduce emissions globally, which will require a global climate treaty and effective policies designed to reduce emissions.

The sites that Sandia manages for the DOE on the North Slope of Alaska and adjacent Arctic Ocean provide our researchers with a rare window into the cloud and radiative processes that take place in Earth's atmosphere at high latitudes. This information is so desirable that the DOE SC has allocated additional funding through its Office of Biological Environmental Research (BER) to (1) improve its Barrow, Alaska, facilities and (2) purchase equipment for another Atmospheric Radiation Monitoring site at Oliktok Point.

Recently completed improvements include an automatic radiosonde balloon launching facility and an X-band radar at Barrow. Oliktok Point will host Doppler and high-spectral-resolution lidars, radar, and radiometers, along with meteorological equipment and other sensors. A hangar there also shelters unmanned aerial vehicles and tethered balloons, which will increase the scope of atmospheric data collection. These new measurement capabilities will provide more comprehensive data on clouds, aerosols, and visible and infrared radiation, while also monitoring sea ice conditions—improving the accuracy and reducing possible sources of error in climate models. We will host collaborators and scientific users who seek to access the Arctic atmosphere.

Our North Slope operations are also important operationally because we are now working to expand our climate/atmospheric research activities to include Antarctica. Our operational knowledge/ experience from our North Slope research efforts will be a valuable asset as we explore partnership opportunities to expand our climate research activities to the southern polar regions.
We have also established a measurement and modeling program to characterize GHG sources by emissions sector. These capabilities are targeted at climate treaty verification and policy support and will also be relevant to Arctic sensitivities to GHG and black carbon emissions.

3 Develop a technical approach for achieving DOE's goal of economical carbon capture, use, and sequestration, including $40/ ton carbon capture.

The Climate Security program seeks to provide technology options to reduce/mitigate carbon's impact on the atmosphere by removing CO_2 from power generating plant emissions and industrial sites and keeping it out of the atmosphere for a very long time. Carbon capture and storage (CCS) technologies seek to capture emitted CO_2; compress it; and transport it to suitable permanent storage sites, such as deep underground.

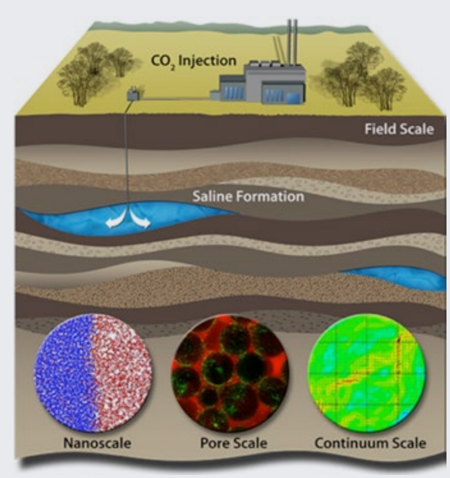
Because industrialized societies produce such a great CO_2 emission volume to be captured, any significant remedy must be implemented on an industrial scale, i.e., it

Understanding Subsurface Processes for Carbon Sequestration

The Center for Frontiers of Subsurface Energy Security (CFSES) is pursuing a scientific understanding of subsurface processes to ensure safe and economically feasible storage of CO_2 without harming the environment. Our vision is to develop and validate models useful for making accurate predictions of the essential subsurface phenomena over very large temporal and spatial scales. CFSES integrates and expands the scientific knowledge of physical, chemical, and biological processes from the molecular to the field scale using experimental and modeling approaches.

Through a partnership between the University of Texas at Austin and Sandia, an extraordinary combination of skilled investigators, extensive facilities, and proven research capabilities in the geosciences, engineering and applied mathematics is represented. For example, Sandia's Geomechanics Laboratory, a DOE Technology Deployment Center, is being used for extensive mechanical measurements for both reservoir and cap rocks to feed into modeling efforts. The CFSES has published almost 40 peer-reviewed articles in high-impact multidisciplinary journals.

Sandia's recent contributions include, "Molecular simulations of carbon dioxide and water: Cation solvation." This work used classical molecular-dynamics simulations to understand the dissolution of the metal cations in a water-liquid CO_2 system. At a larger scale, "Highly parameterized inverse estimation of hydraulic conductivity and porosity in a three-dimensional, heterogeneous transport experiment," demonstrated that high-dimensional parameterization can recover complex details heterogeneous sands and predict tracer transport results. Research performed as part of CFSES is helping to develop a technical approach for achieving DOE's goal of economical carbon capture, use, and sequestration.



CFSES geomechanics modelers are developing codes to understand subsurface processes at all scales relevant to developing safe, environmentally sound, and economically feasible CO_2 storage.

must be cheap. To date, a large CCS market has not developed, but CO_2 is a useful material for many other industrial processes. Reaching the $40/ton price mark will be sufficient to cover the cost of CCS activities and drive a viable business.

CCS is in a relatively early phase of development, with several key questions remaining unanswered, including about its costs, timing, and relative attractiveness vs other carbon-lowering opportunities. Our researchers are investigating two major issues.

- Effective, economical carbon capture is a difficult engineering proposition with current technologies. How to "pluck" the molecule from an industrial emission stream and prepare it for the next step in the CCS process can be addressed through our materials science, systems engineering, and modeling and simulation capabilities.
- ECIS is also using its geotechnical and systems engineering expertise to examine the geology of sequestration. For example, a major use for CO_2 today is for enhanced oil recovery (EOR, CO_2 is injected into a reservoir to maintain pressure and improve oil displacement), but questions remain, i.e., will CO_2 used for EOR stay sequestered?

Sandia's resources and capabilities in basic research such as geoscience, material science, advanced simulation, probabilistic risk assessment, dynamic simulation, and at the CRF that, while developed for other purposes such as underground repositories, the NW program, and automobile efficiency research, can be applied to CCS problems.

4 Develop frontier fossil energy resources, such as shale gas and oil, through advanced resource characterization and production methods that mitigate environmental impacts.

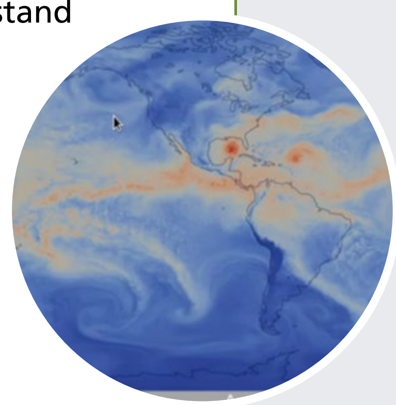
In general, natural gas has approximately half of the carbon-emission footprint of coal. Recent breakthroughs in in exploration/extraction technologies (horizontal drilling and hydraulic fracturing) have made vast deposits accessible for economic energy production. Our Climate Security researchers will apply their geotechnical, modeling, and systems engineering expertise to understand the implications of this new resource for national energy independence and for the climate. We will initiate several systems studies to identify where we

High-Resolution Climate Models

Sandia plays a key role in the development of the Community Earth System Model (CESM), a comprehensive climate model coupling state-of-the-art atmosphere, ocean, land, and ice model components, developed in collaboration with National Science Foundation and DOE laboratories. It is one of the primary tools used in DOE climate change assessments and U.S. contributions to the IPCC assessment reports.

Through the support of DOE/BER, Sandia is leading an effort to develop a next-generation spectral element dynamical core for the CESM atmosphere component model. This work improves the numerical conservation and fidelity of the atmospheric component while also obtaining unmatched parallel scalability leading to record-setting computational performance. High-resolution (~13 km grid spacing at the equator) climate simulations can now be run efficiently on the current DOE petascale and upcoming multi-petascale computers.

High resolution is one of the key requirements needed assess U.S. security impact risks by modeling climate and human response at the regional level with quantified uncertainty. The spectral element dynamical core has been included as an option in the CESM since version 1.0 and was made the default dynamical core in the November 2012 CESM 1.1 release (http://www.cesm.ucar.edu/models/).



Snapshot of precipitable water simulated by the CESM running at 13 km resolution using the spectral element atmosphere dynamical core. The image shows a category 5 hurricane in the Gulf of Mexico with another tropical cyclone forming in the mid-Atlantic. At these resolutions the model has the ability to capture hurricanes not present in lower resolution simulations.

might have the most impact, what's likely to evolve, and where we can contribute to advancing the environmentally responsible use of these vital energy resources.

5 Create a strategic approach to growing the water security program to a critical mass commensurate with the strategic significance of the issue.

Water is important to our domestic economy. In addition to its obvious uses in agriculture and the average citizen's everyday life, it is intimately related to the energy cycle. Its scarcity in the American west can be a limiter on energy generation and/or a significant cost driver. These implications also apply to water issues in the international arena. It can be a key economic limiter and a driver for security issues: where water shortages exist, societal stability and security are often precarious.

Many programs throughout Sandia work to stabilize international relations and reduce conflict. Our Climate Security water research programs can work in a complementary fashion with these other efforts to promote stability and security around the globe.

A difficulty in this research area is that no single federal sponsor exists to coordinate water security studies. Leadership is fragmented, with portions existing in different federal entities as water resource issues impinge on their primary responsibilities. The Climate Security program is working to define a strategic approach to water security issues. To answer questions like, "How do we build a program?" "Who are significant stakeholders and how do we effectively engage with them?" Of primary interest to our program is an understanding of the dynamics between water and (domestic) energy production.

Stakeholder-Driven Resource Planning for Water, Energy, Food, and Security

Managing water resources for food production was the impetus for the earliest human civilization, and remains an important factor in societal stability today. It will become more important in an uncertain future clouded by climate change and shifting weather patterns.

Drought, famine, poverty, terrorism, disease, conflict, social unrest, and failed states are challenges we must overcome as resources become scarce in many regions of the world. Consistent, sustainable resource (fresh water, energy, food) delivery can mitigate these threats. Just a few critical components can make up the foundations for stable and secure social, economic, and political systems around the world.

Sandia researchers are addressing these issues in projects around the U.S. and the world, including the Aral Sea Basin, Tigris-Euphrates Basin, Libya, the Rio Grande Basin, and the Willamette Basin. These projects allow decisions makers to evaluate trade-offs between the interdependencies of water, energy, and food systems within sustainable ecological boundaries.

Stakeholder-driven projects give ownership to, and get buy-in from, the stakeholders. Our collaboration with many experts across many fields is crucial for a full systems understanding of interactions, interdependencies, feedbacks, and long-term consequences of resource allocation management approaches.

Interactions and interdependencies among Earth systems over time are so complex that they cannot be sorted or well-understood without computer simulations. Models allow stakeholders to conceptualize systems and to evaluate potential consequences of future strategies. The models help develop consensus and are valuable tools for educating policy makers and the public on resource-management complexities.

Training regional scientists and engineers in planning and modeling approaches helps establish regional ownership in models and plans while also expanding regional planning capacity and overall technical capacity.

Infrastructure Security

The Infrastructure Security program develops and applies technologies and analytical approaches to secure the nation's critical infrastructure against natural or malicious disruption.

America's critical infrastructures provide the foundation for the nation's economic vitality, national security, and way of life. They frame citizens' daily lives and support one of the world's highest living standards. The systems, facilities, and functions that comprise these infrastructures are sophisticated, complex, and highly interdependent. They are comprised of physical, human, and cyber assets and have evolved over time to be economical and efficient systems. The increasing interconnections and complexity of these systems, subject to natural hazards and coupled with the new malicious threat environment, have created the need for a focus on interdependencies and the consequences they propagate.

A key objective of the Infrastructure Security program area is to support the preparedness and protection of our nation and society by providing analyses of the technical, economic, and national security implications of the loss or disruption of these critical infrastructures, and assist in the understanding and technology development of infrastructure protection and infrastructure disruption mitigation, response, and recovery options.

The nation's energy infrastructure, particularly electricity and hydrocarbon fuels, is of special interest because it faces two foundational challenges as we seek to forge a path toward an energy independent and secure future. First, elements of the infrastructure, such as the electricity transmission and distribution T&D network, have not significantly changed since their initial creation over a century ago. It is clear that new approaches are required for the grid to accommodate the integration of intermittent renewable energy sources such as solar and wind. Second, the reliability and resilience of our energy distribution is central to our national security. For example, robust and secure electrical power is essential to domestic military installations.

The programs of the Infrastructure Security program area work to fully understand, sustain, improve, and where necessary revitalize, the interconnected network of energy delivery systems. Sandia's modeling and analysis capabilities allow us to understand the infrastructures' performance under unusual conditions, the effects of interdependencies, and the dynamics of their interconnections. To better understand the complexities of the interconnected infrastructures, we collaborate with private sector infrastructure experts to develop methodologies and tools for characterizing and simulating their performance.

America's energy infrastructure doesn't stop at its borders. A significant portion of the nation's liquid hydrocarbon fuels is imported from areas of the world subject to rapid social and political upheaval. This upheaval can jeopardize key facilities that process these fuels. This program area includes work addressing the protection of key fuel processing facilities and their supporting infrastructure by providing evaluation, physical protection training, and expert advice to the owners and operators of these international facilities.

As America's infrastructures have become more complex and interconnected, their operation and control has become more complicated. Automated control systems, called supervisory control and data acquisition systems, networked across the Internet have been widely deployed to operate these infrastructures. These systems, and the Internet over which they handle information, are an identified security vulnerability for the infrastructures they control. The Infrastructure Security program area works with several government agencies in the area of cybersecurity to ensure the integrity and availability of the nation's cyber infrastructure.

The performance of the nation's infrastructure is an essential component of the nation's economic prosperity. Through its programs and projects, the Infrastructure Security Program Area seeks to endow the infrastructure with five characteristics: security, reliability, safety, sustainability, and cost effectiveness.

Infrastructure Security Goals

1 Increase the resilience of U.S. and key global critical infrastructure systems by providing increased understanding of interdependencies and risk.

America's continuing economic prosperity depends on its infrastructure. But more than that, in a modern society, where just-in-time delivery applies not only to manufacturing and industry but to energy and food supplies as well, our urban population's very survival also depends on critical infrastructures.

Infrastructure disruption can come from many causes—some natural, some accidental, and some that are maliciously intentional.

Hurricane Katrina showed us how the disruption of the gulf-states petroleum infrastructure has national repercussions. The September 11th attacks were essentially localized, but have had acute and long-term effects on a national and international scale. When the Interstate 35W bridge collapsed in Minneapolis, it took three months to clear the debris from the Mississippi. If that collapse had happened on the lower Mississippi, the disruption of barge traffic up and down the river could have had similar national consequences. America has endured these disruptions before and will again.

Critical infrastructure, infrastructure whose disruption

Effective cybersecurity is transparent to the legitimate network user, but secure against emergent threats from malicious agents.

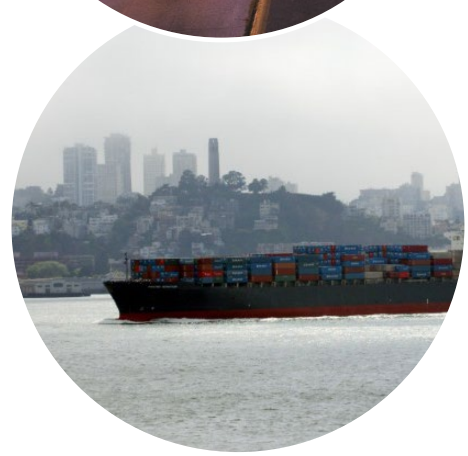
will put many lives at risk, suffers not only under the threat of direct interruption but also from disruption via the interruption of another element of the infrastructure on which it depends. The nation must be prepared for disruption to its critical infrastructure—and in order to do this, we must understand the interdependencies between the infrastructure's disparate systems. We must understand if some systems are more at risk than others and why. We need to know if evolving interdependencies increase or change the risks to critical systems. Are the trends toward more vulnerable conditions/configurations? Or less? How will critical infrastructure disruptions impact national security?

Understanding the linked, interdependent nature of the nation's critical infrastructure in order to enhance preparedness, protection, response, recovery, and mitigation is a hard problem—one that requires the capabilities of a national laboratory. It is through high-performance computing (HPC) modeling and analysis that Sandia can quantify and qualify the interactions of political, health, social, economic, and technical systems. Simulation can couple the effects of socioeconomic systems (power networks, distribution systems, transportation links) to physical systems (climate, weather, geology, geography) to understand large, complex data sets and capture nonlocal, nonintuitive interdependency effects at multiple simultaneous scales and resolutions. By studying these infrastructure systems and their effects on each other in simulation, we can advise policy makers and industry stakeholders on how to mitigate disruption effects and build resiliency into the national system.

2 Grow critical cyber security capabilities within DHS with Sandia as the enduring development partner.

The Department of Homeland Security (DHS) has the mission of protecting civilian federal government information networks against a full range of threats. Government networks and servers are repositories of vast amounts of information that, if stolen, could compromise Americans' physical safety and security as well as their privacy and financial security. As the U.S. benefits from the past few decades' technological advances, we increase our dependence on interconnected devices and systems. This dependence creates vulnerabilities, which might be exploited by adversaries ranging from criminal organizations through nation states. The complexity of these interconnected systems and the rate of technological change cries out for a national-lab-level approach to mitigate the risks to our government systems and our critical computer infrastructures.

Sandia's goal is to develop game-changing cybersecurity capabilities to support DHS's mission of securing the nation's ".gov" domain and defending critical



Mesa del Sol and the Microgrid Concept

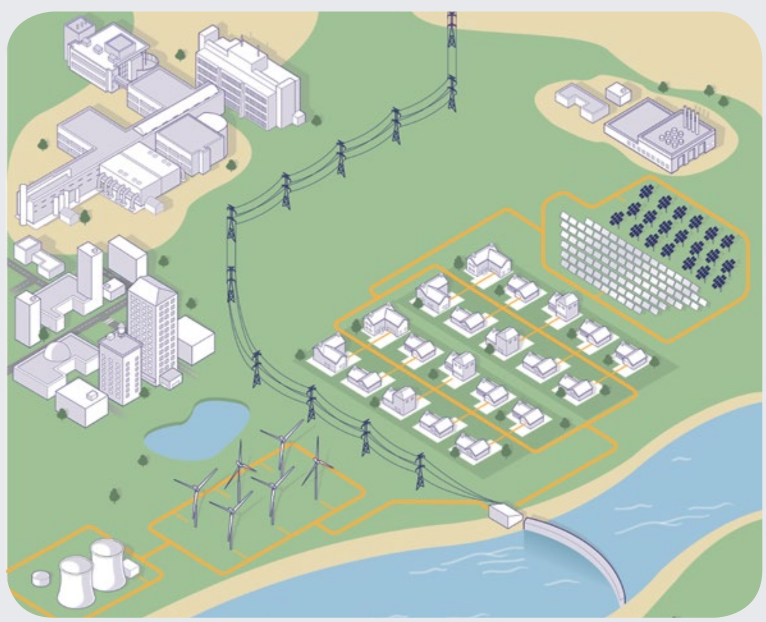
The Mesa del Sol commercial microgrid project is a collaboration that demonstrates improved localized control of generation, distribution, storage, and demand management; improved information use for load smoothing and a more resilient grid; and a nationally replicable technology integration. The Aperture Center building's (see photograph) integrated energy controls are demonstrating a commercial-scale microgrid with photovoltaics (PV), fuel cells, combined heat and power, advanced load controls, and advanced energy-storage components. As the Mesa del Sol community continues to grow, it will further implement these technologies.

The Mesa del Sol project is a collaboration among several partners, each of which provides unique technology strengths to the overall product. It is led by Japan's New Energy and Industrial Technology Development Organization (NEDO), which sponsors several Japanese companies' participation. NEDO funds the hardware and software development and provides overall project management, with Sandia's project contributions funded by DOE.

Sandia is applying research and technology-development capabilities to help the partnership demonstrate efficient, intelligent, and sustainable electricity generation and energy management. Sandia's projects include a collaborative smart-grid and grid-integration effort with PNM and UNM, anti-islanding performance testing of selected Japanese- and U.S.-developed advanced energy management systems, implementing solar resource forecasting with UNM, and a display center for visualizing NEDO smart-grid system performance.

Above:The Aperture Center is a 78,000-square-foot mixed-use commercial building at the center of Forest City's Mesa del Sol model sustainable community. It is the heart of a planned community with 18 million square feet of office, retail, and industrial space and 4,400 acres for residential development.

Right: A microgrid manages multiple distributed electricity generation and storage resources via intelligent load controls and metering. It promotes sustainability by using renewable power generation and storage to optimally balance energy production, storage, and demand within a local region.



infrastructures (e.g., the electric grid and other energy infrastructure) from cyber-based vulnerabilities. We will evaluate systems with the potential to impact critical infrastructures for supply-chain vulnerabilities and create mitigation strategies for supply-chain-induced risks. We will devise strategies to extend cybersecurity beyond government assets to the telecommunications providers, industry partners and subcontractors, and to global partners. Lastly, we will develop a scalable process to assess and improve the cybersecurity performance of government agencies and critical infrastructures, with the objective of providing agencies a mechanism for sharing threat, compromise, and mitigation data.

Our goal is to build/use a threat model in order to guide development, acquisition, and operation of a protective system. The complexity and scale of this system will be unprecedented; it must scale over a wide range of attributes: network size, data sensitivity, communications capacity, geographical distribution, and operational authorities. Sandia is contributing to the solution by providing architectural designs based on threat models. We are providing much needed scalability to the efforts to address the cyber risks. We are tackling the big problems, like the supply-chain risk, which are so challenging as to be largely deferred by the other contributors to cybersecurity.

Sandia is partnering with the University of Vermont and an array of Vermont stakeholders (utility companies, private industry, residential and industrial consumers, policymakers, and regulators) to create a test bed of the nation's first statewide, 21st century energy infrastructure. This Vermont initiative will require innovation in a broad spectrum of areas including Sandia's cybersecurity competencies.

3 Establish at Sandia and DHS the capability (people, processes, and tools) to bring physical and cyber risks under a common risk-management framework.

The last couple years have brought increased recognition of the impact of the cyber threat to the nation's critical infrastructure. The Department of Homeland Security has the responsibility to address this cyber-physical connection. Sandia has established programs and relationships with the two key DHS entities in this domain:

the Office of Cybersecurity and Communications (CS&C) and the Office of Infrastructure Protection (IP).

Recently, CS&C and IP established two pilot projects with the goals of

1. providing actionable information to critical infrastructure owner/operators and state and local governments, and
2. getting the cyber and physical infrastructure experts to work jointly toward a common outcome.

The execution of these pilots highlighted the need for a common risk approach to evaluate the nexus of cyber and physical threats. Furthermore, the pilots highlighted the critical importance of developing human capital capable of simultaneously addressing cyber and physical threats.

Smart Power Infrastructure Demonstration for Energy Reliability & Security (SPIDERS)

A coalition of government agencies and national laboratories is working to increase electric power surety (safety, security, reliability, sustainability, and cost effectiveness) by developing new microgrid architectures that can function independent of the bulk electric grid. Sandia was selected as the lead designer for SPIDERS, leveraging our decade of experience with microgrids.

SPIDERS goals for electric power surety at U.S. military installations are to

1. protect critical infrastructure from power loss should the bulk electric grid suffer physical or cyber disruptions;
2. provide reliable backup power during emergencies by integrating renewables and other distributed generation;
3. ensure that critical operations can be sustained during prolonged outages; and
4. manage electrical power and consumption more efficiently—reducing petroleum demand, carbon emissions, and transportation costs.

The first SPIDERS microgrid will be implemented at Joint Base Pearl Harbor Hickam in Honolulu—the final design and construction process is underway. The second installation, at Fort Carson, is much larger and more complex and will integrate an existing 2 MW of solar power, several large diesel generators, electric vehicles, and large-scale electrical energy storage. Camp H.M. Smith, the most ambitious project, will rely on solar and diesel generators to power the entire base.

The SPIDERS template, while currently being implemented at military installations, is ultimately intended for a broader cross-section of the U.S. economy and to help both the public and private sectors become more resilient.

Microgrid

A small-scale version of a bulk electrical grid; implemented at a local level and taking advantage of locally generated power sources (PV, small wind, biomass, small hydro, combined heat and power, and energy storage). A microgrid can be tied to the larger grid, yet retains the ability to independently supply energy in the event the larger grid experiences power interruptions or price fluctuations.

By instituting energy security policies and implementing renewable energy generation/use at its bases in the U.S. and abroad, the military can reduce our national dependence on foreign energy supplies and prototype/prove systems that can then be marketed to commercial and residential consumers.

There is also new Administration guidance to transform Infrastructure Protection into Infrastructure Resilience. This will require an evolution of the existing "risk frameworks" into a "risk-informed resilience" framework.

These transitions provide an important opportunity for Sandia to increase its impact. Sandia has established a reputation with DHS as a thought leader on infrastructure resilience. The Infrastructure Security program's goal is to develop a common "language" between the physical and cyber domains: appropriate norms, reference values, and common framework that allow customers to perform tradeoffs between the risks incurred in either the cyber or the physical space. To do this, the Infrastructure Security program is following a two-pronged approach

1. engaging with senior leadership at DHS National Protection and Programs Directorate, CS&C, and IP, providing information about capabilities and gaps, and making recommendations and
2. developing a comprehensive Sandia internal approach that connects and develops our expertise in cyber, physical infrastructures, risk, and resilience.

Sandia has a golden opportunity to exemplify the new priorities. At times, Sandia's current programs and activities have mirrored the divisions between its various sponsors. This Infrastructure Security goal specifically addresses the increased national impact that Sandia can have by integrating internally. Furthermore, it recognizes that the new capability should not reside just at Sandia, and that Sandia must work with its DHS partners to deploy and engrain it in their ability to deliver their new mission.

4 Develop and implement a comprehensive Sandia program to support the modernization of the U.S. electric grid, with a focus on security and resiliency.

Our nation's energy infrastructure faces two foundational challenges as we seek our vision toward an energy independent and secure future. First, the electricity T&D network have not significantly changed since their initial creation over a century ago. It is clear that new approaches are required for the grid to accommodate the integration of intermittent renewable energy sources such as solar and wind. Second, the reliability and resilience of our grid is central to our economic and national security. Robust and secure power is essential to key infrastructures that support our national defense and economy. Electricity outages presently cost our economy over $150B annually.

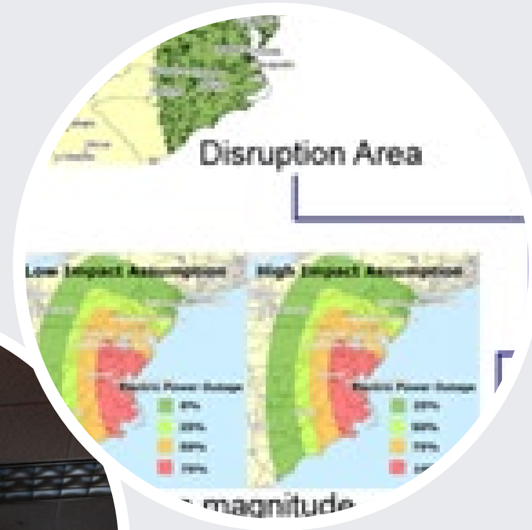
Modernizing our electrical grid is a tremendous undertaking, requiring the coordination and collaboration of a wide range of stakeholders spanning federal and local governments, the energy industry, electric utilities and—perhaps most importantly—the myriad of consumers.

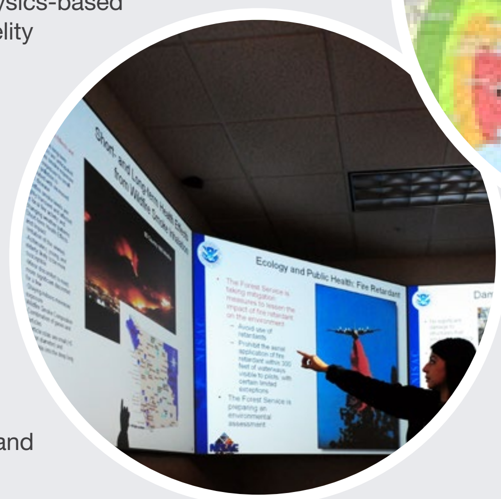
The American Recovery and Reinvestment Act (ARRA) program in 2009 made an initial and significant step toward grid modernization. Over $10B of investment was made in smart-grid build outs. Those investments are rapidly being implemented, and there is now a great opportunity to build on the ARRA program toward true grid modernization.
Sandia supports the DOE, DHS, and DoD efforts to modernize the electric grid by providing R&D of new transformational energy technologies; analyses of the technical, economic, and national security implications of the loss or disruption of critical civilian and military energy infrastructures; and assisting in the understanding and technology development of infrastructure protection and infrastructure disruption mitigation, response, and recovery options.

National Infrastructure Simulation and Analysis Center (NISAC)

NISAC is a Department of Homeland Security (DHS) modeling, simulation, and analysis program comprising personnel in Washington, D.C., Sandia, and Los Alamos, and jointly led by Sandia and LANL. NISAC prepares analyses of critical infrastructure and key resources (CIKR). NISAC provides analyses of interdependencies and consequences of infrastructure disruptions across all 18 CIKR sectors at national, regional, and local levels. NISAC developed/employs tools, including process-based systems dynamics models, mathematical network optimization models, physics-based models of existing infrastructures, and high-fidelity agent-based simulations of systems.

Physical, human, and cyber assets make up CIKR infrastructures. The complexity of these systems, subject to natural hazards, coupled with the new threat environment, has created a need for a focus on interdependencies, vulnerabilities, and the consequences a failure propagates. NISAC supports the preparedness and protection of our nation by providing analyses of the technical, economic, and national security implications of the loss or disruption of CIKR, and assist in understanding infrastructure protection, mitigation, response, and recovery options.





Infrastructure disruption models.

5 Develop end-user relationships to accelerate infrastructure and cyber solutions for security and resiliency.

Infrastructure- and cyber-related problems are so complex that solutions will require unprecedented collaboration between governmental, regulatory, and industry stakeholders. As an federally funded R&D center, Sandia is uniquely positioned to work collaboratively with key policy makers, while protecting the proprietary interests of infrastructure owners/operators. The Infrastructure Security program has an important opportunity to enable holistic infrastructure security and resilience through industry engagement. The Infrastructure Security program can achieve widespread impact from its work through industry partners, as infrastructure owners/operators deliver secure and resilient solutions to the nation’s critical infrastructures through their products and consumer networks.

Through partnerships, Sandia provides expertise and technology to meet industrial needs. By applying Infrastructure Security program capabilities to industrial problems, Sandia gains new perspectives on national infrastructure and cyber issues; and industry can market more robust, new, and/or improved products. This benefits ECIS as well as other Sandia national security mission applications. Industry partnerships are also the primary mechanism for commercializing Infrastructure Security program technologies in meeting mission sponsors’ expectations.

Industrial partnerships in the Infrastructure Security program can range from collaborating on basic R&D to commercializing mature technologies. In some cases, infrastructure owners/operators come to Sandia with well-defined needs, for which the Infrastructure Security program can provide discrete access to existing technologies and capabilities (examples of current and emergent opportunities, which are not UUR, might include: utilities and indepent system operators, Coca-Cola, Northrop Grumman, Boeing, Heinz, Archer Daniels Midland, etc.). In other cases, Sandia participates in industry and regional cross-sector coalitions (e.g., DHS Sector Coordinating Councils, Bay Area Science & Innovation Consortium) to gain a better understanding of existing and imminent infrastructure challenges. With an intimate understanding of key infrastructure challenges, Sandia can partner directly with infrastructure owners/operators, or work with risk analysis providers, to improve knowledge and tools (e.g., a cooperative R&D agreement with Aon, CRISTAL/FASCAT). Finally, Sandia also works through its government partners to test and validate commercial solutions (e.g., DHS S&T Cyber Transition to Practice).

The importance of industrial partnerships to the Infrastructure Security mission is reflected in the ECIS ten-year objective to: "Accelerate U.S. industry's innovation, development, and successful deployment of energy solutions to the nation's most challenging problems through seamless integrations of Sandia's science, engineering, and security expertise by leveraging and integrating across our U.S. government-sponsored programs and relationships and by partnering with industry academia and other labs.

Enabling Capabilities

The Enabling Capabilities program area provides a differentiating science understanding that supports ECIS SMU and Sandia National Laboratories mission technologies now and into the future.

Enabling Capabilities is unique among ECIS' four program areas. The other three areas each focus on one (albeit large) research area to bring Sandia's research and engineering capabilities to bear on the problem and help the nation forge a solution. The Enabling Capabilities program area is organized to cut across the ECIS areas with a capability base to support all ECIS goals as well as provide a science base, which supports and integrates with other SMUs. The scientists and engineers in the Discovery Science and Engineering activity pursue fundamental research that has applications in multiple program areas. Because Enabling Capabilities has connections interwoven throughout Sandia, this discovery science can easily find more than one application.

Enabling Capabilities also pushes to rapidly advance connectivity of scientific breakthroughs to real-world applications delivered by industry. Congress established an Advanced Research Projects Agency—Energy (ARPA-E) within the DOE to be a catalyst for transformation, and to do so with fierce urgency. Our nation's history is replete with examples of pioneers and entrepreneurs who took risks. These innovators often failed initially, but quickly learned from those failures, competed against each other, and innovated in both technology and business to create the largest industrial base the world has ever seen. ARPA-E's goal is to tap into this truly American ethos, and to identify and support the pioneers of the future. With the best R&D infrastructure in the world, a thriving innovation ecosystem in business and entrepreneurship, and a generation of youth that is willing to engage with fearless intensity, we have all the ingredients necessary for future success. The ECIS ARPA-E activity is tasked with working with the scientists and engineers of the ECIS program areas to form partnerships with industry, academia, and entrepreneurs to develop research proposals that will win grant awards from ARPA-E.

The Laboratory Directed Research and Development (LDRD) program at Sandia has invested a portion of the program on low-to-midscale technology readiness levels that advance our understanding and capabilities to solve problems in the nation's energy, climate, and infrastructure security sectors. Enabling Capabilities has the responsibility to lead this portion of the LDRD program for the ECIS SMU—the ECIS LDRD Investment Area—and this forms the third focus area in the Enabling Capabilities program area.

Groundbreaking Work on Criegee Intermediates

In a breakthrough January 2012 Science paper, researchers from Sandia's Combustion Research Facility, the University of Manchester, and the University of Bristol report direct measurements of gas-phase Criegee intermediate reactions using photoionization mass spectrometry.

Criegee intermediates are implicated in autoignition chemistry and are pivotal atmospheric reactants—but only indirect knowledge of their reaction kinetics had previously been available. This collaboration's direct measurements determined rate coefficients for Criegee reactions with key species, such as sulfur dioxide and nitrogen dioxide, and provided new insight into these transient molecules' reactivity.

Criegee intermediates are isomers of more stable molecules – i.e., they contain the same set of atoms, but arranged in different order. Detecting and measuring reactions of Criegee intermediates was enabled by a Sandia-designed apparatus that uses the intense, tunable light from Lawrence Berkeley National Lab's Advanced Light Source to discern the formation and removal of different isomeric species.

The team's kinetics results imply a much greater Criegee intermediate role in tropospheric sulfate and nitrate chemistry than models had assumed, a conclusion that will substantially impact existing atmospheric chemistry mechanisms. Because sulfur dioxide oxidation by Criegee intermediates is much faster than modelers thought, these reactions may be a major tropospheric sulfate source, changing tropospheric aerosol predictions.

This breakthrough capability was funded by the Office of Basic Energy Sciences (BES) within the DOE's Office of Science and conducted using the Advanced Light Source, a BES-supported scientific user facility.

Sandia combustion researchers Craig Taatjes (left) and David Osborn discuss data found from detecting and measuring Criegee intermediate reactions. The apparatus was used to make the measurements, which researchers believe will substantially impact our understanding of atmospheric

The final focus area in Enabling Capabilities recognizes the importance of policy decisions and government regulations—and how these impact our nation's security. As a national laboratory, Sandia has the responsibility to bring its capabilities to bear as a resource to help decision makers craft the strategies and policies. In many cases, we are required to advance the current state of capabilities in order to address the most challenging questions being debated. Further, we have the responsibility to use our analysis capabilities to examine a systems view—weaving together interconnected activities that are complex and adapting to their environment, whether it be man-made or deriving from nature. The Systems Analysis and Policy activity takes a complex, adaptive system-of-systems approach to forge meeting points between research efforts in the ECIS SMU and throughout the nation's energy, climate, and infrastructure research enterprise to foster a larger view among the participants.

Enabling Capabilities Goals

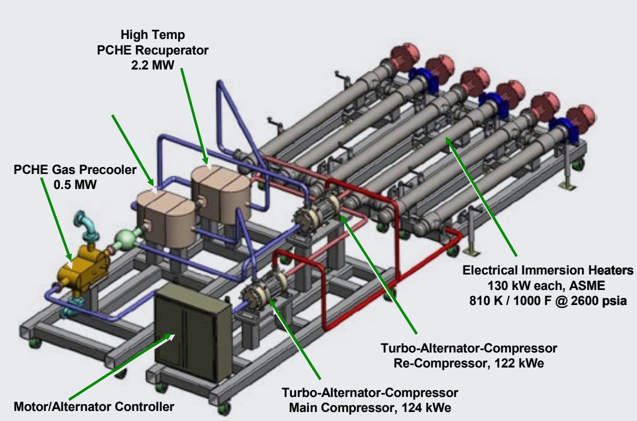
1 Nurture discovery science for fundamental breakthroughs and deepen our competencies in key strategic areas that enable ECIS mission objectives and goals.

Our nation faces serious, looming challenges in the areas of energy, climate, and infrastructure security, on which this document has focused. The ECIS SMU scientists and engineers apply their expertise to the challenges described at the beginning of this strategic plan. However, focused, applied research and analysis can only bring us so far. Many of the challenges cannot be solved with improvements to current technologies or extrapolations from them—they require discovery and an understanding of the foundational characteristics of materials, energy, and their interactions.

Supercritical CO_2 and the Brayton Cycle

Sandia is researching advanced supercritical CO_2 (S-CO_2) Brayton cycle power conversion systems for a new breed of electricity generating stations. The S-CO_2 Brayton cycle takes advantage of non-ideal gas behavior at the critical point of 31 °C to achieve efficiencies near 50% at 700 °C. The combination of lower temperatures, high efficiency, and high power density (in this regime, S-CO_2 is near water's density) allows us to develop very compact, transportable systems that are affordable because they require only standard engineering materials (stainless steel), less material is required, and because the small size allows for advanced, modular manufacturing processes.

After construction and functional testing at Barber-Nichols Inc. the split flow, fully recuperated S-CO_2 Brayton cycle loop arrived at the Nuclear Energy Systems Laboratory (NESL) in April 2012. The relocated loop was commissioned by August and will be extensively tested at Sandia to prove the theoretical electrical conversion efficiency of up to 50%. In August, the NESL Brayton Laboratory was dedicated containing three Brayton cycle loops. The laboratory will be first used to research General Electric's concept for the remainder of CY12. The Brayton Laboratory's next expansion will be a 10 MW_e demonstration with NREL in support of the DOE Sun Shot Power Cycle Program. In addition to the DOE-sponsored research, three industrial customers have already signed up for testing time on the loops. The technology is being applied to solar, geothermal, nuclear, natural gas, coal, and diesel generators.



The split flow, fully recuperated, S-CO_2 Brayton cycle test assembly.

The Enabling Capabilities program area supports this kind of foundational research at facilities such as the

- Center of Integrated Nanotechnologies (CINT),
- MESA (Microsystems Engineering, Science, and Applications) facility,
- CRF (Combustion Research Facility),
- Ion Beam Laboratory,
- Processing and Environmental Technology Laboratory,
- Computer Science Research Institute, and
- Integrated Materials Research Laboratory.

With these facilities, Sandia has extensive, in some cases unique, state-of-the-art laboratory facilities for understanding mathematics, algorithms, and software codes; material growth; fabricating microsystems; semiconductor processing; and characterizing structural, electronic, and optical materials. The combination of facilities is unparalleled anywhere in the world.

In addition to special lab facilities and equipment, we have cultivated substantial personnel expertise, in parallel, over decades, in a broad range of mathematics and physical science, chemistry, materials science, and engineering disciplines. This collection of expertise—that can be brought together into large, comprehensive teams—is very rare.

It is through the use of these facilities by our collection of unique scientific and engineering capabilities that we can understand and develop the foundational scientific principles of novel materials and processes into the technology of tomorrow that can surmount the challenges that we face in energy, climate, and infrastructure protection that can secure and sustain our nation.

In all of the Enabling Capabilities efforts, we seek out collaborative partnerships with other institutions in order to better leverage all available capabilities. A shining example of this collaborative spirit is CINT, which we cohost with

LANL. Sandia will continue to nurture and grow this relationship and expand CINT's impact on Sandia's mission areas and our partnerships with industry. Another area in which Sandia can nurture and support discovery science is in our extensive HPC capacity that brings closer together in co-design the architecture of the computing machine with the ECIS problem to be solved. Sandia seeks to expand the role and impact of HPC into a wider range of DOE/Sandia mission areas (energy, climate, infrastructure assurance) that position Sandia in a leadership role for the DOE complex in exascale planning and execution that is integrated across both Advanced Scientific Computing Research and Advanced Scientific Computing programs.

2 Accelerate industry development of transformational energy technologies through ARPA-E.

The widespread use of fossil fuels has long driven the engine of economic growth and, consequently, has significant national security implications. Looking toward the future, the nation that successfully grows its economy with more efficient energy use, a clean domestic energy supply, and a smart energy infrastructure will lead the global economy of the 21st century. ARPA-E was created within DOE to be a catalyst for such a transformation, and to do so with fierce urgency. ARPA-E has rapidly created a portfolio of transformative R&D projects targeted to address the nation's technological gaps and create new paradigms for energy sector solutions. Sandia can help accelerate innovation by engaging current and future ARPA-E innovators that otherwise might not benefit from our intellectual resources and relevant capabilities. Our strategy involves three simultaneous approaches:

1. build relationships with current ARPA-E investigators on projects where we can add value;
2. explore partnerships with innovators in the group of highly-ranked but unfunded ARPA-E proposals to pursue scientifically sound, high-risk R&D of keen interest to ARPA-E; and
3. contribute technical leadership to ARPA-E to shape future directions as this agency becomes established within DOE.

3 Pioneer advanced electrical energy storage technologies and develop new technologies for enhanced battery safety and reliability, through scientific research in materials and chemistry, and innovative architectures and cell designs.

We perform R&D that creates options for advancing electrochemical energy storage in stationary and transportation applications. A particular Sandia strength is the capability base to assure reliability and safety of components and systems. This capability draws upon deep scientific roots in the integration of theory, experimentation, modeling, and analysis. In order to expand our impact we seek and support partnerships from across the customer program areas, with other national labs, academia, and industry. An example of such a partnership is the Joint Center for Energy Storage Research (JCESR) which is a DOE Hub led by Argonne National Laboratory. A focus of this goal is to advance our understanding of materials performance in batteries such that we can determine quantitative performance of multiple battery technologies sufficiently to predict their failure mechanisms, lifetimes, and new design principles for future battery options that operate in stressing environments.

4 Enable analysis capabilities to inform and influence the nation's debate on energy strategy and policy.

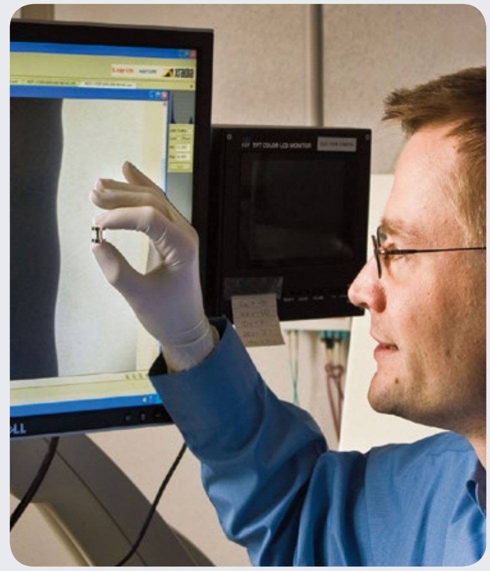
The ECIS LDRD investment area focuses on R&D that advances our capability base and creates a differentiating expertise that

Dan Sinars Honored by President Obama for Early Career Accomplishments

President Barack Obama named ECIS researcher Dan Sinars as a recipient of the Presidential Early Career Award for Scientists and Engineers (PECASE). This is the highest honor bestowed by the U.S. government on outstanding scientists and engineers who are early in their independent research careers. Dan is among 96 researchers (including 13 from DOE laboratories) from 11 federal agencies named PECASE recipients in 2012.

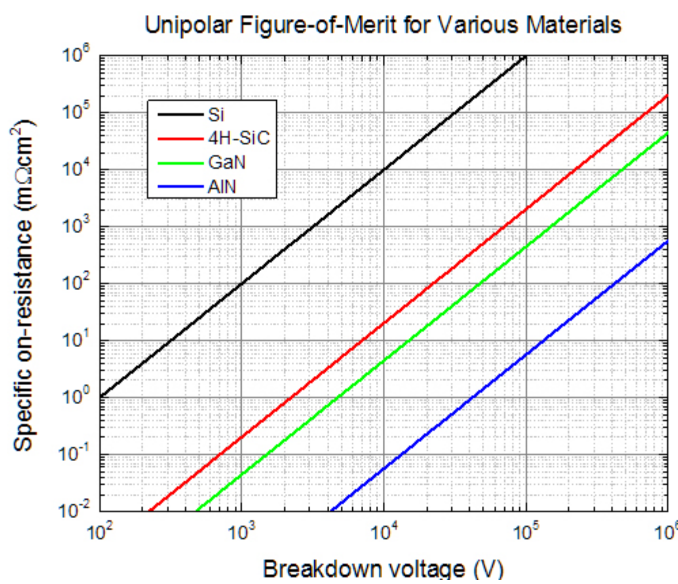
Dan was nominated by DOE's Office of Science "for developing innovative techniques to study the properties of instabilities in magnetized-high-energy-density plasma, enabling quantifiable comparison between experiment and simulation needed for validating cutting-edge radiation-hydrodynamics codes, and for demonstrating substantial leadership qualities in high-energy-density-laboratory-plasma physics."

Dan works on Sandia's "Z machine," and leads experiments that use the large magnetic pressures created by pulsed currents to create the conditions to fuse ions through a process known as inertial confinement fusion. These experiments could lead to high fusion energy yields in the laboratory and possibly electrical energy generation in the future. Dan's team was the first to capture, in a series of images separated by nanoseconds, the undesirable but apparently unavoidable appearance of a damaging instability (called Magneto-Rayleigh-Taylor, or MRT) on the Z-machine. These data are critical to developing successful physics models of magnetically driven implosions on Z.



Sandia researcher Dan Sinars was recognized for developing innovative techniques to study the properties of instabilities in magnetized-high-energy-density plasma.

we bring to the nation. One important focus in the LDRD portfolio of work creates advanced systems analysis capabilities for the ECIS SMU and demonstrates that advancement through use. We build upon this capability base to perform analyses that allow us to engage strategic decision makers at the national and state levels. The decision makers either influence debate about energy, climate, and infrastructure policy or are actively creating that policy. A goal of Sandia National Laboratories is to become a visible national presence and a resource for energy policy decision makers. We seek to be recognized for providing the context for energy strategy and policy decisions in terms of technology options as well as tradeoffs in policy options.



The plot shows that aluminum nitride (blue line) promises an ~5 order of magnitude improvement in performance over silicon-based semiconductors (black line)—if we can solve the materials-physics issues.

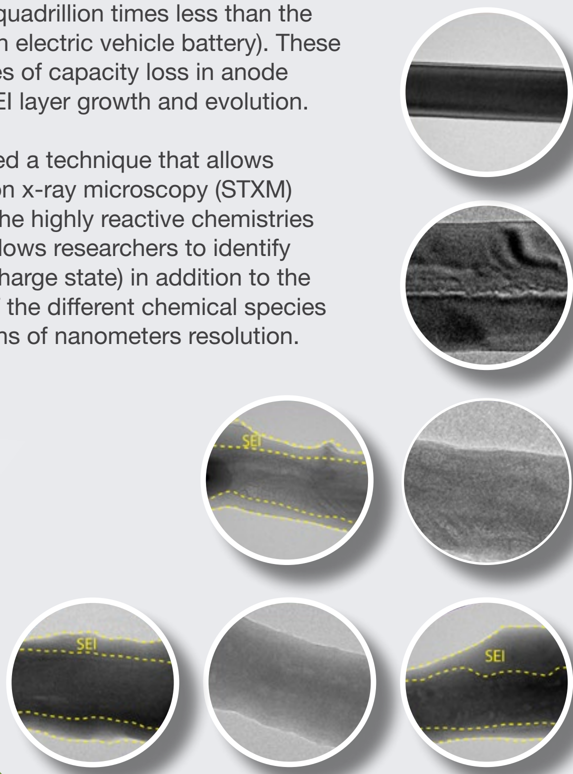
Battery Reliability Science

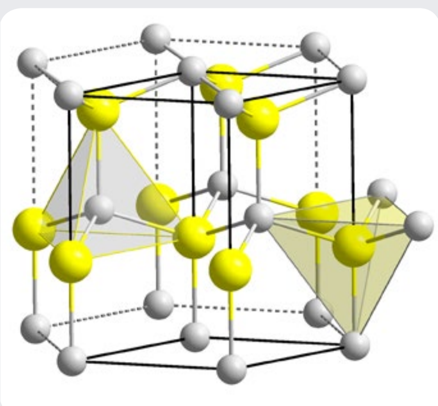
In December 2010, Sandia was home to breakthrough transmission electron microscopy (TEM) work that directly observed changes in atomic structure of a SnO_2 nanowire as it underwent lithiation. This experiment demonstrated the power of in situ TEM for directly observing structural changes and the resulting battery-material degradation during charge-discharge cycling. The goal is to quantitatively monitor charging-discharging of a battery's nanoscale electrode materials in the presence of the liquid electrolyte and directly observe degradation process effects, such as fracture or thickening of the electrolyte decomposition product layer, known as the solid-electrolyte interphase (SEI).

Understanding materials' physical changes during charge-discharge can lead to improved electrode architecture, enabling improvements to efficiency, energy density, reliability, safety, and lifetime. Sandia's in situ TEM lithiation experiments are now able to view single nanoscale battery particles and—in a capability unique to Sandia—control and detect charging-discharging currents at the level of femtoAmperes (a quadrillion times less than the charging current in an electric vehicle battery). These studies reveal sources of capacity loss in anode materials, such as SEI layer growth and evolution.

Sandia also developed a technique that allows scanning transmission x-ray microscopy (STXM) to be used to study the highly reactive chemistries in batteries. STXM allows researchers to identify the chemical state (charge state) in addition to the spatial distribution of the different chemical species in the battery with tens of nanometers resolution.

Quantitative nanoscale electrochemistry reveals evidence of capacity loss due to SEI thickening using in situ TEM.





The wurtzite crystal structure of zinc oxide and aluminum nitride.

Sandia's Wide Bandgap (WBG) Semiconductor Research

WBG semiconductors have electronic bandgaps significantly greater than those of the more commonly used semiconductors, silicon and gallium arsenide. Higher energy gaps allow electronic power switching devices to operate at higher temperatures and larger voltages, while reducing weight and volume and improving efficiency. The WBG semiconductors also bring the electronic transition energy into visible light's energy range. Hence, light-emitting diodes (LEDs) can be made that emit in the visible spectrum, for LED lighting, or even the ultraviolet.

Sandia's WBG semiconductor capabilities encompass

- atomic-precision materials synthesis and characterization;
- device processing, design, and fabrication (planar and nonplanar);
- computational modeling of materials and device physics (including reliability and failure analysis); and
- system-level integration and testing.

This capabilities suite is unique among national laboratories in its degree of vertical integration—from materials growth to systems-level integration and testing—and hence in its ability to support collaborations and innovation.

Sandia researchers are studying aluminum gallium nitride (AlGaN) -based alloys because of their ability to produce power-switching devices of very high stand-off voltages and efficiencies, but several phenomena must be more fully understood before AlGaN can be effectively deployed into electric vehicle and electric grid power-switching applications. For example, the measured breakdown voltage of AlGaN is much less than theoretical predictions. Other challenges for AlGaN power deviced include growth on AlN substrates for vertical devices, low non-compensated n-type doping, minority-carrier transport, and obtaining high-reliability gate dielectrics.

Key Facilities

Many of Sandia's unique research facilities are available for use by industry, universities, academia, other laboratories, state and local governments, and the scientific community in general. User and collaborative facilities are a unique set of scientific research capabilities and resources whose primary function is to satisfy DOE programmatic needs, while being accessible to outside users.

The National Solar Thermal Test Facility (NSTTF) primary goal is to provide experimental engineering data for the design, construction, and operation of unique components and systems for proposed solar thermal electricity generating plants, which have three generic system architectures: line-focus (trough and continuous linear Fresnel reflector systems), point-focus central receiver (power towers), and point-focus distributed receiver (dish-engine systems). The NSTTF's solar tower is the only test facility of its kind in the U.S. Comprised of a 200-foot-high tower and over 200 heliostats that track the sun to focus up to 6 MW of concentrated sunlight toward the top of the tower. The NSTTF can provide high heat flux and temperatures for materials testing or aerodynamic heating simulation; large fields of optics for astronomical observations or satellite calibrations; a solar furnace; and a rotating platform for parabolic trough evaluation. The NSTTF is sponsored by the DOE Office of Energy Efficiency and Renewable Energy (EERE); significant recent infrastructure improvements were funded by the ARRA.

The Joint BioEnergy Institute (JBEI) is a San Francisco Bay Area scientific partnership led by Lawrence Berkeley National Laboratory (LBNL) and including Sandia, the University of California campuses of Berkeley and Davis, the Carnegie Institution for Science, and LLNL (Lawrence Livermore National Laboratory). JBEI is sponsored by the DOE SC with a mission to advance the development of the next generation of biofuels—liquid fuels derived from the solar energy stored in plant biomass. JBEI is focused on the efficient conversion of lignocellulosic biomass, the most abundant organic material on the planet, into these biofuels. JBEI is organized into four divisions: Feedstocks, Deconstruction, Fuels Synthesis, and Technologies.

The Combustion Research Facility (CRF) is an internationally recognized DOE SC-sponsored collaborative research facility. CRF scientists, engineers, and technologists conduct basic and applied research aimed at improving our nation's ability to use and control combustion processes. Research ranges from studying chemical reactions in a flame to developing laser diagnostics for combustion-science research. Most of the CRF's work is done in collaboration with scientists and engineers from industry and universities. Visiting researchers collaborate with the CRF staff and bring with them experience and knowledge that enhances and brings new approaches to collaborative research.

Sandia's Battery Abuse Testing Laboratory (BATLab) is at the forefront of testing the limits of what batteries can safely handle and provides critical data for developing the next generation of batteries—doing everything imaginable to batteries (e.g., crushing, piercing with nails, heating to boiling) in the lab to make sure that once a battery is in commercial use, it will be safe and reliable. The BATLab tests cells from the size of a laptop computer battery up to packs weighing several hundred pounds. The BATLab team has been recognized for its ability to perform scientific analysis and a full range of measurements. The BATLab is sponsored by DOE EERE.

Supercomputing Capability

The **Red Sky supercomputer** debuted as the 10th fastest supercomputer on the Top500 list, with a sustained performance of 429.9 teraflops and an estimated power usage effectiveness of 1.035. Red Sky is intended to be a capacity machine. It wasn't designed with the full-system job as its target, but to run many smaller jobs. With Red Sky, Sandia wanted a design that could accommodate a higher degree of scalability than is typical in the HPC world. Red Sky is intended to be broadly available to the entire Laboratory and to outside collaborators.

The **National Infrastructure Simulation and Analysis Center (NISAC)** is a DHS-sponsored modeling, simulation, and analysis program comprising personnel in Washington D.C. and from Sandia and Los Alamos national laboratories. NISAC analyzes critical infrastructure and key resources, including their interdependencies, vulnerabilities, consequences, and other complexities. NISAC provides strategic, multidisciplinary analyses of interdependencies and the consequences of infrastructure disruptions across critical infrastructure and key resource sectors at national, regional, and local levels. NISAC experts have developed and are employing tools to address the complexities of interdependent national infrastructures, including process-based systems dynamics models, mathematical network optimization models, physics-based models of existing infrastructures, and high-fidelity agent-based simulations of systems.

The **Photovoltaic Systems Evaluation Laboratory (PSEL)** is a multiuser, multisponsor facility that conducts research in PV cells, modules, and arrays and performs detailed, comprehensive analysis in PV systems design, optimization, characterization, and performance in real-world scenarios and delivers highly accurate predictive models for PV devices. Long-term test facilities at PSEL, along with accelerated lifecycle test capabilities elsewhere at Sandia, enable researchers to identify failure modes, characterize degradation processes and engineer solutions that will improve PV system lifetimes. PSEL conducts research on behalf of the DOE, DoD, and other customers, often in collaboration with industry/academic partners. PSEL supports developing domestic and international standards that reduce market barriers to greater adoption of solar technologies while also improving operator/installer safety as well as system reliability and functionality. PSEL's testing, analysis, and validations provide unbiased evaluations of current and proposed standards. PSEL also has a demonstrated history of appropriately handling proprietary data.

The **National Supervisory Control and Data Acquisition (SCADA) Test Bed** is a DOE Office of Electricity Delivery and Energy Reliability-sponsored resource to help secure our nation's energy control systems. It combines state-of-the-art operational system testing facilities with research, development, and training to discover and address critical security vulnerabilities and threats to the energy sector. Sandia R&D efforts range from autonomous agent systems applied to SCADA, to cryptographic security, system assessment, and red-team activities. Sandia is able to complement its communication and control capabilities with actual generation and load facilities for distributed energy resources.

The **Center for Integrated Nanotechnologies (CINT)** is determining the scientific principles that govern the design, performance, and integration of nanoscale materials. CINT's emphasis is on exploring the path from scientific discovery to the integration of nanostructures into the micro and macro worlds. This involves exploring, experimentally and theoretically, nanoscale behavior; developing many synthesis and processing approaches; and understanding new performance regimes, testing new designs, and integrating nanoscale materials and structures. Integration is key to exploiting nanomaterials, and the scientific challenges that it poses are at the heart of CINT's DOE SC-sponsored mission. Our activities bring together university faculty, students, other national laboratory scientists, and industrial researchers to propose, design, and explore integrating new nanoscale materials into novel architectures and microsystems.

The Distributed Energy Technologies Laboratory (DETL) conducts research with industry and academic partners to integrate emerging energy technologies into new and existing electricity infrastructures. DETL's DOE EERE-sponsored research spans generation, storage, and load management at the component and systems levels and examines advanced materials, controls, and communications to achieve a reliable, low-carbon electric infrastructure. DETL's reconfigurable infrastructure simulates many real-world scenarios (e.g., island and campus grids, remote operations, and scaled portions of utility feeders and the transmission infrastructure), including both three-phase 480 V and single-phase 240/120 V, to support integration testing and system demonstrations. Power signals can be supplied by AC and/or 200 kW DC simulators, as well as from a variety of (continuous or intermittent) generation sources. Electrical storage capabilities include a lead-acid battery bank and a test pad on which other energy storage devices can be staged. Over 350 kW of programmable resistive loads can be combined with programmable inductive, capacitive, and motor loads. DETL researchers analyze the effects of high penetration of renewable technologies and distributed energy on the grid and resolve issues of grid interconnectivity, controls, security, safety, performance, reliability, and interoperability. DETL testing can assess compliance with Underwriter Laboratories, International Electric Code, and other standards, and DETL research provides core technical understanding to form the basis for new standards.

The Scaled Wind Farm Technology (SWiFT) Facility, hosted at Texas Tech University, is a recently initiated facility which is being developed to enable rapid, cost-efficient testing and development of transformative wind energy technology. SWiFT's objectives are to reduce power losses and damage caused by turbine–turbine interaction, enhance energy capture and damage-mitigation potential of advanced rotors, and improve the validity of aerodynamic, aero-elastic and aero-acoustic simulations used to develop innovative technologies. SWiFT consists of three research-scale wind turbines with the potential to add seven additional turbines. These turbines are heavily instrumented with state-of-the-art control and data-acquisition systems featuring site-wide time synchronization based on GPS. SWiFT is funded by DOE EERE to perform research testing for both collaborative and highly proprietary projects with industrial, governmental, and academic partners.

The Atmospheric Radiation Monitoring (ARM) Climate Research Facility sites on Alaska's North Slope provide data on clouds, aerosols, and visible and infrared radiation—improving the accuracy and reducing possible sources of error in climate models. The ARM facility is an Office of Biological and Environmental Research (BER) user facility within DOE's Office of Science providing the climate researchers with strategically located in situ and remote-sensing observatories. BER is funding facilities for another ARM site at Oliktok Point, which will also be managed by Sandia. Oliktok Point will host Doppler and high-spectral-resolution lidars, radar, and radiometers, along with meteorological equipment and other sensors. A hangar will shelter unmanned aerial vehicles and tethered balloons, which will increase the scope of atmospheric data collection.

The photovoltaics (PV) **Regional Test Center (RTC)** at Sandia's NSTTF site, funded by DOE EERE, independently validates 30–300 kW PV system performance and reliability for emerging U.S. manufacturers and develops standardized processes for PV system monitoring/validation—to assure banks, insurance companies, and other stakeholders that new PV technologies will work with high fidelity and robustness over time and meet contractual obligations. The five DOE RTCs are designed to host identical, highly instrumented systems in hot-dry, hot-humid, steppe, and cold-humid climates. The NSTTF RTC leverages Sandia expertise in PV testing, research, performance modeling, and reliability. Together the RTCs demonstrate methods to show whether PV systems are operating as expected and that the systems are sufficiently understood to project performance/reliability in other system configurations and environments. The RTC supports 1 MW of PV systems plus baseline test equipment, labor, and data analysis.

Sandia's **Technical Area III** is five miles south of Sandia's major engineering and administrative complex, and is an approximately 100 mi^2 area reserved for large-scale systems and component testing in high-shock, high-thermal, or high-radiation environments. Test capabilities include high-speed sled tracks; a cable pull-down system; fire and thermal radiation testing capabilities; centrifuges and high-shock linear actuators; and explosives testing areas to asses structural, mechanical, electrical system performance and damage analysis under harsh environments. Each test complex includes sophisticated high-speed digital and visual data monitoring and collection systems to help assess system performance and response in these type of environments. The large-scale liquefied natural gas (LNG) fire and cryogenic damage testing research was conducted in Tech Area III using the Thermal Test Complex as well as individually developed experimental sites.

The Thermal Test Complex evaluates thermal loads from fire environments and the multi-physics response of hardware subject to fires. Funded by the DOE NW program, it houses horizontal and vertical wind tunnels; a full-scale radiant heat laboratory; an abnormal thermal environment lab; and additional laboratory space for fabrication, instrumentation, and diagnostics development, with five test chambers with capabilities to maintain temperatures ranging from –184 °C to 300 °C and three furnaces that can maintain environments up to 1,700 °C—all under specifically controlled relative humidity conditions. Laser diagnostic equipment is used to help understand the burning process. Systems to allow jet fuel, methanol, and other liquid fuels as well as hydrogen, methane, and other gas fuels are part of the facility's design.

Sandia's **Aerial Cable Facility** provides a unique capability to precisely simulate a wide variety of environments in a highly instrumented test arena, including photometrics, laser trackers, and telemetry and hard-wire data-gathering systems. Primary among these environments are drop and high-velocity impact testing, suspension of large items hundreds of feet above the ground, and simulated free flight along an aerial cable. The DOE NW-funded facility has four primary cable systems that span two ridges over a mountain canyon. Each cable is approximately 5,000 ft long and has endpoint anchors about 1,000 ft above the valley floor. At the center of each cable span is a flat test arena about 300 ft in diameter.

The **Rocket Sled Track Facility** provides a controlled environment for high-velocity impact, aerodynamic, acceleration, and related testing. The DOE NW-funded facility uses photometrics, laser trackers, and telemetry and hardwire data-gathering systems. Time-space-position information can be acquired at up to 1 KHz with 1 ft accuracy, and transducer data may be sampled at up to 1 MHz. High-speed video, flash x-ray, and film cameras running 40,000 frames per second and higher are available. Hardened data recorders, for use on board sleds or test items, are also available for test purposes. The facility provides a 10,000 ft track for testing items at very high speeds and a 2,000 ft railroad gauge track for testing very large items. The combination of ingenuity, experience, and instrumentation available at this facility makes it unique for research, test, and evaluation purposes.

Sandia's Leadership in Federal Energy Research Efforts

Sandia also uses the Solar Tower for high-temperature materials tests.

Concentrated Solar Power

CSP offers a utility-scale, firm, dispatchable renewable energy option that can help meet the nation's demand for electricity. Worldwide, CSP activity is rapidly scaling, with approximately 14,500 MW in various stages of development in 20 countries. The DOE EERE's Solar Energy Technologies Program CSP subprogram seeks to lower costs and advance technology to the point that CSP is competitive in the intermediate power market by 2015–2017 and in the baseload power market by 2020–2022. Two national laboratories, NREL and Sandia, manage the R&D support for the U.S. CSP industry with critical R&D to meet cost, reliability, performance, and manufacturability challenges. R&D is conducted through cost-shared contracts with industry, universities, and other national laboratories. In addition, the CSP subprogram develops partnerships with federal and state agencies, as well as throughout the solar industry, to encourage the deployment of CSP technologies by addressing land and transmission issues.

Solid-state light-emitting device (LEDs).

Energy Frontier Research Center for Solid-State Lighting Science

Lighting consumes roughly 22% of U.S. electricity, a roughly $50B/year cost to the U.S. consumer. SSL is an emerging technology with the potential to reduce that energy consumption by a factor of 3–6 times. Despite a decade's enormous progress, however, SSL remains a factor of 5–10 times away from this potential. Sandia's Solid-State Lighting Science (SSLS) a DOE SC Energy Frontier Research Center (EFRC) will accelerate advances in this fundamental science by exploring energy conversion in tailored photonic structures. Drawing on Sandia's long history of SSL R&D, and working closely with its university and industry partners, the SSLS EFRC will

- work to understand the mechanisms and defects in SSL semiconductor materials that presently limit the energy efficiency;
- investigate conversion of electricity to light using radically new designs, such as luminescent nanowires, quantum dots, and hybrid architectures; and
- study energy conversion processes in structures whose sizes are even smaller than the wavelength of light.

Sandia's BATLab tests batteries to failure so that industry can produce safer products.

Energy Storage Systems

Over three decades, the DOE Energy Storage Systems (ESS) research program, managed by Sandia, has evolved successful battery and power sources research, engineering, and testing, especially as storage technologies relate to electric utilities, renewables, and grid security. ESS activities include research over an entire, integrated, battery storage system, including power electronics and controls. From that research, DOE and Sandia project managers have conducted very successful utility storage demonstrations that have resulted in numerous commercial products. The ESS research program includes responsibility for the development of an even broader range of utility-related efforts, including innovative storage technologies such as flywheels and compressed air energy storage. ESS project reports have become the defining documents for the benefits of energy storage and are cited regularly by storage experts around the world. Working in close partnerships with industry, academia, and governments, the ESS Program continues to lead in world-wide efforts that address energy issues through energy storage.

Sandia's programs have long supported technologies and protocols that facilitate nonproliferation and secure control of nuclear materials. Sandia also supports programs that assist Russia to safely manage and control nuclear materials from dismantled Soviet-era weapons systems. Sandia is applying this well-developed capability and recognized leadership in critical infrastructure protection, cybersecurity, and energy systems solutions to enhance national security by helping energy supplier nations secure their critical energy infrastructure.

Modeling shows geospatial structures of pandemic influenza.

National Infrastructure Simulation and Analysis Center

NISAC is a DHS Office of Infrastructure Protection modeling, simulation, and analysis program jointly led by Sandia and LANL, integrating the two laboratories' expertise in the modeling and simulation of complex systems for evaluating national preparedness and security issues. NISAC prepares analyses of critical infrastructure and key resources (CIKR)—providing analyses of interdependencies and consequences of infrastructure disruptions across all 18 CIKR sectors at national, regional, and local levels. NISAC developed/employs tools, including process-based systems dynamics models, mathematical network optimization models, physics-based models of existing infrastructures, and high-fidelity agent-based simulations of systems.

Physical, human, and cyber assets make up CIKR infrastructures. The complexity of these systems, subject to natural hazards, coupled with the new threat environment, has created a need for a focus on interdependencies, vulnerabilities, and the consequences a failure propagates. NISAC supports the preparedness and protection of our nation by providing analyses of the technical, economic, and national security implications of the loss or disruption of CIKR, and assist in understanding infrastructure protection, mitigation, response, and recovery options. NISAC activities include infrastructure modeling and analysis, decision support tools, knowledge management, and fast turnaround analyses.

Ocean Power magazine.net

Ocean Energy

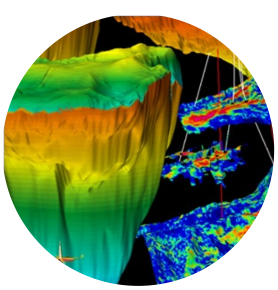
The DOE's Water Power Program supports the development of advanced water power devices that capture energy from waves, tides, ocean currents, rivers, streams, and ocean thermal gradients. Sandia, through a partnership with several national laboratories and academic institutions, leads two of the four topic areas awarded under a $9M grant and will provide technical support in a third topic area. The topic areas are Supporting Research and Testing for Marine and Hydrokinetic (MHK) Energy, Environmental Assessment and Mitigation Methods for MHK Energy, Supporting Research and Testing for Hydropower, and Environmental Assessment and Mitigation Methods for Hydropower. The Sandia-led effort will pursue a diverse research agenda in MHK systems and will collaborate with Argonne National Laboratory and Oak Ridge National Laboratory (ORNL) on conventional hydropower. In partnership with ORNL, PNNL, and NREL. WPP activities will evaluate new device designs and conduct basic research in materials, coatings, adhesives, hydrodynamics, and manufacturing to assist industry in bringing efficient technologies to market.

Smart Power Infrastructure Demonstration for Energy Reliability and Security Joint Capabilities Technology Demonstration

The Infrastructure Program Area of the ECIS SMU is participating in the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) Joint Capabilities Technology Demonstration (JCTD)—a combined agency (DOE, DoD, DHS) demonstration effort for energy security at three military installations. SPIDERS combines several DOE efforts: smart grid, cyber security, energy efficiency, renewable energy, and energy storage via demonstration and early deployment of energy technologies on military installations. ECIS's Infrastructure Program Area is contributing to the design of the microgrids and cyber security architectures of the SPIDERS JCTD. The Army Construction Engineering Research Lab is the Technical Manager for the project. Jason Stamp (6114, Military and Energy Systems Analysis) serves as the Deputy Technical Manager. Sandia is the lead systems engineering lab (among five overall DOE labs).

Strategic Petroleum Reserve

The 727-million-barrel U.S. SPR is the largest stockpile of government-owned emergency crude oil in the world. Established in the aftermath of the 1973–74 oil embargo within the DOE Office of Fossil Energy, the SPR provides the President with a powerful response option should a disruption in commercial oil supplies threaten the U.S. economy and it provides a national defense fuel reserve. The SPR stores crude oil in solution-mined salt domes because they offer the lowest-cost, most environmentally secure way to store crude oil for long periods of time. Because the salt caverns are 2,000–4,000 feet below the surface, geologic pressures seal any cracks that develop in the salt formation, assuring that no oil leaks. The natural temperature difference between the top of a cavern and the bottom (a distance of around 2,000 feet) keeps the crude oil continuously circulating, giving the oil a consistent quality. Sandia is the technical leader for geology, geomechanics, and computational modeling issues related to the SPR.



Sandia's geologists and modelers work together to help SPR officials understand the nature of underground salt domes.

Industrial Partnerships Strategy

Industrial partnerships are key to achieving our mission objective of accelerating U.S. industry's innovation, development, and successful deployment of energy solutions to the nation's most challenging problems.

Energy-related problems are so complex that solutions and the successful implementation of solutions depend on collaboration with and reliance on industrial partners. Widespread impact of the SMU's work is achieved through industry partners—as industry delivers solutions to the nation's energy problems through their products and infrastructure. Sandia provides our partners unique expertise and technology leading to more robust, new or improved products. In return, Sandia gains new perspectives on national energy, climate, and infrastructure issues, as well as new or improved technology from the application of ECIS capabilities to industrial problems. The capability improvements benefit not only ECIS, but other Sandia national security missions as well. Industry partnerships are also the primary mechanism for commercializing ECIS technologies.

The importance of industrial partnership to the ECIS mission is reflected in our ten-year objective to:

accelerate U.S. industry's innovation, development, and successful deployment of energy solutions to the nation's most challenging problems through seamless integrations of Sandia's science, engineering, and security expertise by leveraging and integrating across our U.S. government sponsored programs and relationships and by partnering with industry academia and other labs.

SMU industrial partnerships should lead to one or more of the following outcomes for every ECIS program area:

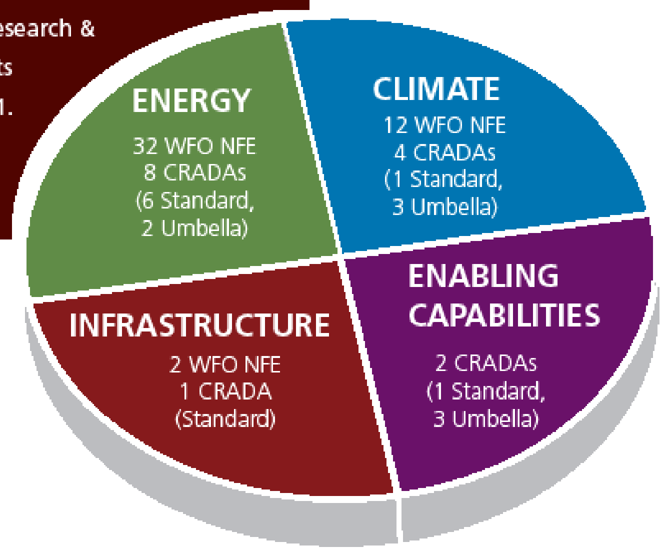
- Sandia research and technology incorporated into industry's products and infrastructure,
- industry advocacy for ECIS mission programs and research,
- industry insights that enable Sandia to effectively direct research, and
- industry's insights and support that establishes Sandia as a provider of technically sound and objective information to policy makers.

The specific outcome(s) desired from industry vary across the ECIS program areas and even within subprograms. As such, each program identifies and pursues specific industrial partners that can help achieve its goals and objectives. Securing these partners require that the expertise and technologies offered by ECIS significantly improves industry's ability to deliver to their customers. That is, the partner must have a strong reason for wanting to work with Sandia. Once the partnerships are in place, ECIS must work intensely to meet deliverables on the time scales required by industrial competition.

Although the types and numbers of industry partners vary across ECIS program areas, each area targets a few key partners. These targets reside in the nuclear power industry, the automotive industry, the petroleum industry, public utilities, the power generation sector, the physical security sector, the renewable energy sector, and the cyber infrastructure sector.

ECIS Industry Portfolio by Program

Current industry portfolio includes Work for Others (WFO), Non-Federal Entities (NFE) and Cooperative Research & Development Agreements (CRADAs) as of April 2011.



Others will also emerge as industry engagement progresses. In the near- and long term, the ECIS SMU is committed to developing key partnerships with industry to ensure its strategic objectives, goals, and milestones are met.

Clean Combustion Engines Advanced with Predictive Simulation Tools

Sandia has been working with General Motors (GM) for over 30 years. In the last few years, this partnership has become a strategic alliance, which includes a cooperative research and development agreement (CRADA), making it easier for the partners to work together.

The alliance has broken new ground in how the national laboratories work with industry leaders. We support a dedicated Sandia liaison to GM and a GM liaison to Sandia—to create continuity and facilitate communication between appropriate individuals in the two large, complex organizations. This model expedites collaborations on key technologies and systems analysis to address the most critical issues including working to strengthen U.S. positions in energy efficiency, energy security, technology innovation, and global competitiveness.

Research focuses on systems modeling for energy, infrastructure, and future-generation vehicles; energy storage: advanced batteries and hydrogen storage; clean advanced combustion; and future generation vehicle networks and sustainable communities. Combustion is an area that GM and Sandia have worked on extensively over the years. Currently, we are addressing clean advanced combustion using many technologies and may include the Predictive Simulation of Internal Combustion Engines (PreSICE) in the future.

Because of their relatively low cost, high performance, and ability to use renewable fuels, internal combustion engines—including those in hybrid vehicles—will continue to be critical to our transportation infrastructure for decades. Achievable advances in engine technology can improve the fuel economy of automobiles by over 50% and trucks by over 30%.

The use of predictive simulation tools for enhancing combustion engine performance will result in direct economic benefit through reduced time-to-market and reduced development costs. Dramatic increases in fuel efficiency will increase the nation's energy security and simultaneously reduce greenhouse gas emissions.

A PreSICE workshop with participants from industry, including GM, the national laboratories, including Sandia, and universities was held in March 2011 to identify research needs. While workshop participants agreed enhanced efficiency is achievable, they also agreed that dramatic increases in engine efficiency can only be reached by developing new design tools that fully leverage the computational simulation capabilities of the nation.

The final appropriation for the DOE Office of Science in 2012 included $10M for this effort. GM-Sandia strategic alliance will be a key partnership helping to achieve PreSICE program goals.

Sandia researcher Daniel Dedrick handles a complex metal hydride within an inert production & storage environment.

Sandia and GM researchers study a combustion simulation. Our rich collaboration history results in cleaner, more efficient combustion engines on the road today than would have otherwise been.

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Acronyms

ARPA-E	U.S. DOE Advanced Research Projects Agency–Energy
ARM	Atmospheric Radiation Monitoring
ARRA	American Recovery and Reinvestment Act of 2009
ATLAS II	Accurate Time-Linked data Acquisition System
BATLab	Battery Abuse Testing Laboratory
BES	U.S. DOE Office of Basic Energy Sciences
CCS	carbon (dioxide) capture & storage (or sequestration)
CESM	Community Earth Systems Model
CIKR	critical infrastructure & key resources
CINT	Center for Integrated Nanotechnologies
CRADA	cooperative research and development agreement
CRF	Combustion Research Facility
CS&C	DHS Office of Cybersecurity and Communications
CSP	concentrated (or concentrating) solar power
DBHD	deep borehole disposal
DETL	Distributed Energy Technology Laboratory
DHS	U.S. Department of Homeland Security
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
ECIS	Energy, Climate, & Infrastructure Security
EERE	DOE Office of Energy Efficiency & Renewable Energy
EFRC	Energy Frontier Research Center
EOR	enhanced oil recovery
ESS	Energy Storage Systems (DOE research program)
FY	fiscal year
GHG	greenhouse gas
HPC	high-performance computing
IEA	International Energy Agency
IP	DHS Office of Infrastructure Protection
IPCC	Intergovernmental Panel on Climate Change
JBEI	Joint BioEnergy Institute
JCESR	Joint Center for Energy Storage Research
JCTD	joint capabilities technology demonstration
LANL	Los Alamos National Laboratory
LBNL	Lawrence Berkeley National Laboratory
LDRD	Laboratory-Directed Research & Development (program)
LLNL	Lawrence Livermore National Laboratory
LNG	liquefied natural gas
MELCOR	Methods for Estimation of Leakages & Consequences of Releases
MEMS	micro-electronic & micro-electromechanical systems
MESA	Microsystems Engineering Science & Applications (facility)

MHK	marine & hydrokinetic
NEDO	New Energy & Industrial Technology Development Organization (in Japan)
NFE	nonfederal entity
NISAC	National Infrastructure Simulation & Analysis Center
NNSA	National Nuclear Security Administration
NRC	U.S. Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
NSTTF	National Solar Thermal Test Facility
NW	nuclear weapon(s)
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
PreSICE	Predictive Simulation of Internal Combustion Engines
PSEL	Photovoltaic Systems Evaluation Laboratory
PV	photovoltaic(s)
PWh	petawatt-hour
R&D	research & development
RTC	(DOE-sponsored PV) Regional Testing Center
S&T	science & technology
S2P	Sunshine to Petrol (program)
SC	DOE Office of Science
SCADA	supervisory control and data acquisition (systems)
S-CO_2`	supercritical CO_2
SES	Stirling Energy Systems (of Phoenix, Arizona)
SMR	small, modular reactor
SMU	Strategic Management Unit
SPIDERS	Smart Power Infrastructure Demonstration for Energy Reliability & Security
SPR	U.S. Strategic Petroleum Reserve
SSL	solid-state lighting
SSLS	Solid-State Lighting Science (center)
SWiFT	Scaled Wind Farm Technologies (Facility)
T&D	transmission and distribution
UQ	uncertainty quantification
VAWT	vertical-axis wind turbine
WFO	Work for Others (type of contract)
WPP	Water Power Program (DOE research program)

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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